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London

Science & Technology in Britain

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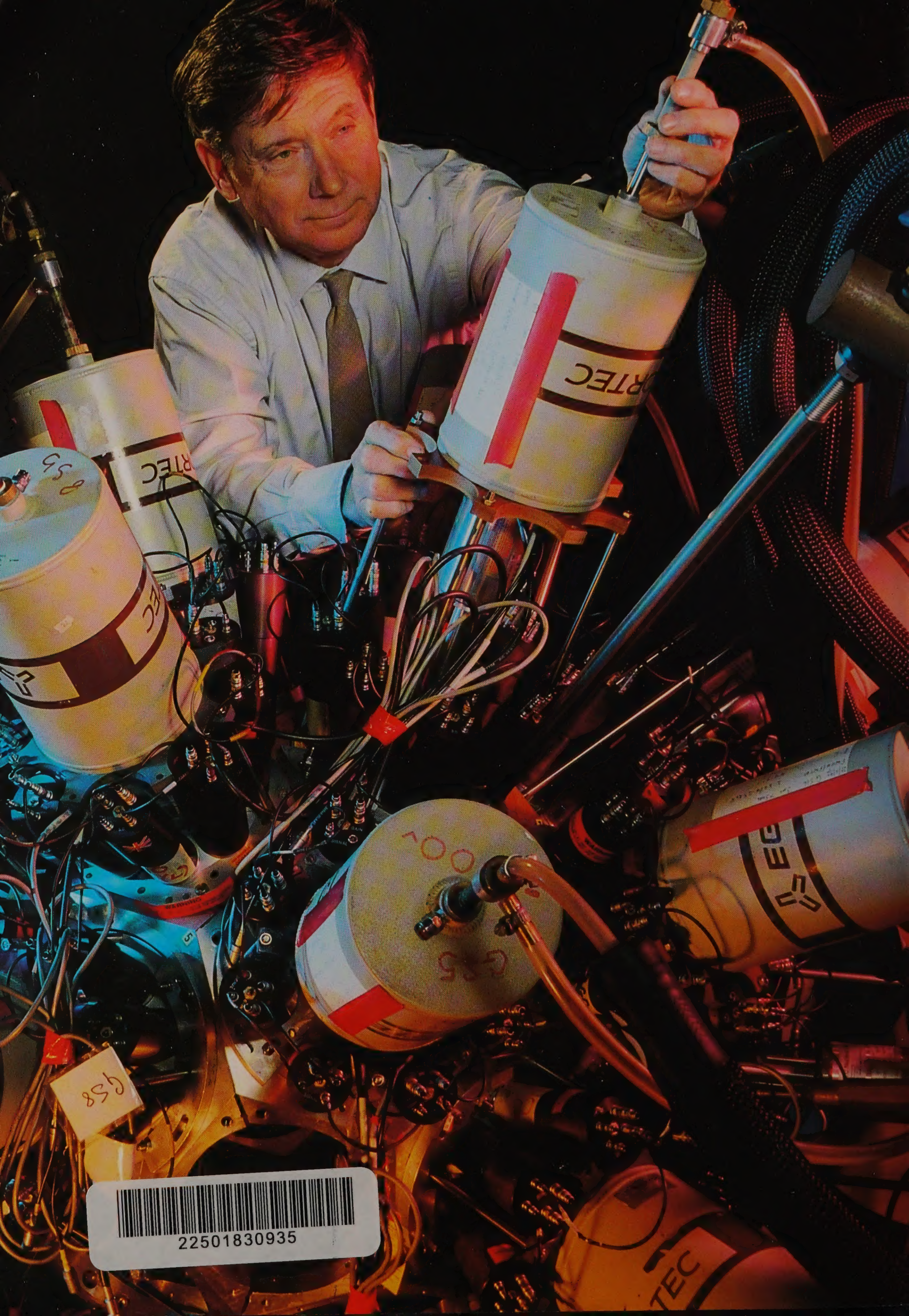

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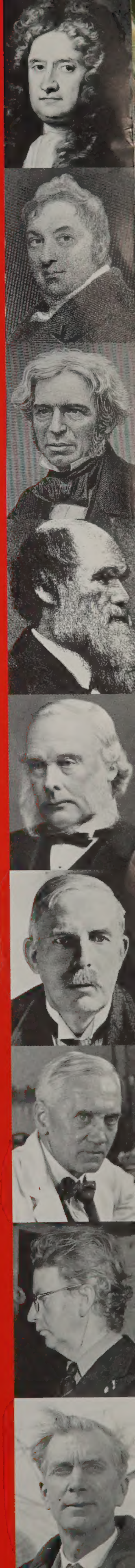
A physicist at Manchester University, with an array of gamma ray detectors to be used in a joint project with Brookhaven National Laboratory in the United States to study new nuclei with large excesses of neutrons. His Nuclear Group's research now involves collaboration with scientists in Europe, the United States and Australia.



From the top,
Sir Isaac Newton
1642 – 1727
who formulated laws of motion and the law of gravitation;
Edward Jenner
1749 – 1823
pioneer of vaccination;
Michael Faraday
1791 – 1867
'the father of electricity,' pioneered photochemistry, electro-chemistry and the liquefaction of gases;
Charles Darwin
1809 – 1882
first to formulate the theory of evolution by natural selection;
Lord Lister
1827 – 1912
the founder of antiseptic techniques in surgery;
Lord Rutherford
1871 – 1937
who pioneered the science of nuclear physics;
Sir Alexander Fleming
1881 – 1955
discoverer of penicillin;
John Logie Baird
1888 – 1946
pioneer of television;
Sir Martin Ryle
1918 – 1984
who pioneered the science of radio-physics.

The term 'Britain' is used in this publication to mean the United Kingdom of Great Britain and Northern Ireland; 'Great Britain' comprises England, Wales and Scotland.

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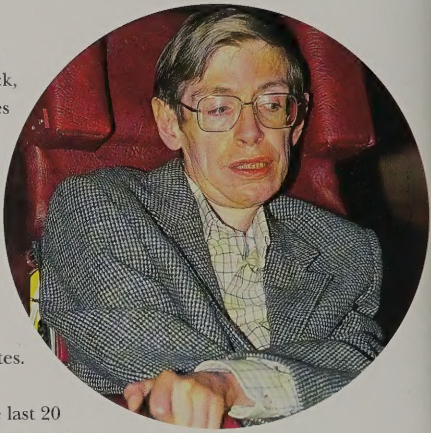
Introduction



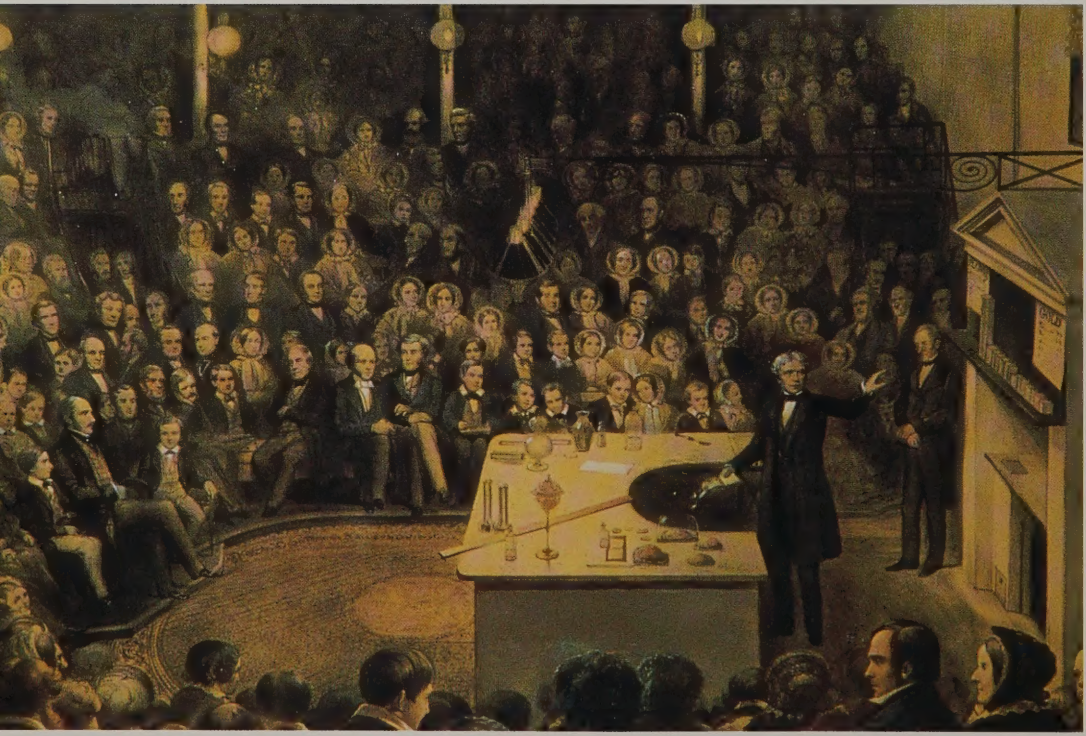
Professor Stephen Hawking (b. 1942), leading theoretical physicist in the field of general relativity and the theory of 'black holes'.

BRITAIN has a long tradition of research and innovation in science, technology and engineering in universities, research institutes and industry. Its record of achievement is in many ways unsurpassed, from the contributions of Isaac Newton to physics and astronomy in the 17th century (theory of gravitation and three laws of motion) to the work of Charles Darwin on the theory of evolution and the inventions of Michael Faraday in the 19th century (the first electric motor, generator and transformer).

Great medical advances include the development of immunisation by Edward Jenner in the 18th century and the founding of antiseptic surgery by Lord Lister in the 19th. This record has been maintained throughout the 20th century. There are few branches of science, engineering and technology in which Britain has not excelled. For example, fundamental contributions to modern molecular genetics were made through the discovery of the three-dimensional molecular structure of deoxyribonucleic acid (DNA) by Francis Crick, Maurice Wilkins, James Watson of the United States and Rosalind Franklin in 1953. Nobel prizes for science have been won by 70 British citizens – more than any other country except the United States.

Other notable contributions over the last 20 years have been made by Stephen Hawking in improving the understanding of the nature and origin of the universe; Brian Josephson in superconductivity (abnormally high electrical conductivity at low temperatures); Martin Ryle and Anthony Hewish in radio-astrophysics; and Godfrey Hounsfield in computer-assisted tomography for medical diagnosis.

Much pioneering work was done during



Michael Faraday, delivering a lecture in 1856 in the presence of the Prince Consort and the Prince of Wales at the Royal Institution. His work led directly to the development of the transformer and later the dynamo, without which the generation and distribution of electricity could not have proceeded.

the 1980s. For example, in 1985 British Antarctic Survey scientists discovered the hole in the ozone layer over the Antarctic, while Alec Jeffreys invented DNA fingerprinting, a forensic technique which can identify an individual from a small tissue sample. The first combined heart, lungs and liver transplant was carried out at Papworth Hospital, Cambridge, in 1986.

More recently there have been several breakthroughs in genetics research, including the identification of the gene on the Y chromosome responsible for determining sex, and the identification of other genes linked to diseases, such as cystic fibrosis and the commonest form of inherited heart disease.

A vaccine has been developed in Britain to protect against cancer associated with the Epstein-Barr virus. Gene therapy has begun on the treatment of cystic fibrosis. The world's first pig with a genetically modified heart has been bred by scientists at Cambridge University, an important milestone in breeding animals as organ donors for people.

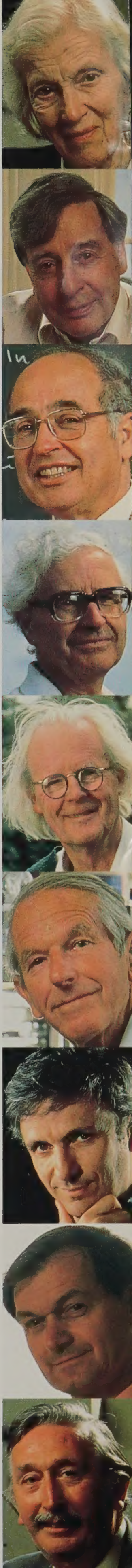
Science, engineering and technology are fundamental to the economic success of any internationally competitive country. Education, health care, the environment, manufacturing industry services and the quality of life all increasingly benefit from the work of scientists, engineers and technologists. The research carried out in Britain's publicly funded higher education institutions and research institutes forms a vital contribution to the health of the economy and the country's future industrial development.

As a source of inventions and ideas and highly trained manpower, these institutions are required to play an increasing role in technological innovation, thereby increasing industrial competitiveness and addressing social and cultural needs. A range of government support and award schemes exists to bring research out of the laboratory and into the market place.

However, the Government considers that public funding should primarily support the pursuit of basic scientific knowledge, while industry should bear the main responsibility for the commercial development of scientific advances. The Government's major strategy document outlining future policy on science, engineering and technology, *Realising Our Potential,* was published in 1993 (see p. 4) and stresses the need for closer links between the science base and industry.

Many industries fund their own research and run their own laboratories. Large companies such as ICI, BT (British Telecom) and BP develop new types of products, equipment and processes. Industry also funds university research and finances contract research at government establishments, individual research organisations and contract research organisations. A large amount of funding for research, particularly in medicine, also comes from Britain's charitable organisations.

Britain cannot claim sole credit for all the achievements covered in this booklet and owes much to international collaboration, which has long been a tradition in science and is increasingly important today. Many British research teams are engaged in major programmes in partnership with their overseas counterparts. However, while teams of scientists dominate present-day discoveries in contrast to the pioneering individuals of the past, British academics and inventors continue to make worldwide reputations.



From the top, **Professor Dorothy Hodgkin** who developed the technique of X-ray crystallography; **Professor Robert Edwards** pioneered the techniques for *in vitro* fertilisation; **Sir Michael Atiyah** responsible for K-Theory and the Atiyah-Singer index theorem linking geometry, topology, algebra and calculus; **Anthony Hewish** whose work in radioastronomy led to the discovery of pulsars; **Professor John Maynard Smith** whose discoveries and evolutionary theories applied mathematics to biology; **Dr Frederick Sanger** winner of two Nobel prizes for chemistry; **Michael Green** creator of the concept of superstrings; **Roger Penrose** best known for his fundamental work in general relativity theory; **Sir Godfrey Hounsfield** inventor of computer tomography.

Organisation and Funding

Government Policy and Organisation

A scientist examines a computer contour plot of the COSY (Through Bond) Nuclear Magnetic Resonance spectrum of the enzyme Ribonuclease-B. The peaks in blue and red are due to interactions between protons on adjacent carbon atoms within the molecular structure. Photographed in the Glycobiological Unit at Oxford University, where research into the body's sugar chemistry and its relationship to disease is performed.

THE GOVERNMENT'S science, engineering and technology support aims to advance scientific knowledge and technological capability and to provide training for scientists, engineers and technologists in order to achieve economic, social and cultural benefits for Britain. The Government intends that future spending on research should be much more closely related to meeting Britain's needs and enhancing the capacity for wealth creation.

Scientific and technological issues are the responsibility of a Cabinet minister, the Minister for Science, supported by an Office of Science and Technology (OST) within the Cabinet Office. The OST receives independent advice from eminent scientists, technologists, engineers and industrialists.

The OST is responsible for the government-financed research councils, covering engineering and physical sciences; particle physics and astronomy; biotechnology and biological sciences; medicine; the natural environment; and economics and social science (see p. 8). The OST encourages links between the research councils and organisations using their research, such as industry and government departments.

The research councils, largely financed by the OST, use funds for research in the following ways:

- grants and contracts to universities and other higher education establishments and to research units;
- provision of facilities and technical expertise in support of basic, strategic and applied research programmes;
- funding of research council establishments;
- support for postgraduate study; and
- subscriptions to international scientific organisations.

As the department responsible for government-wide research projects, the OST administers the LINK Scheme, which encourages collaboration between academic and industrial research (see p. 11).

The Council for Science and Technology (CST) brings together industrialists, academics, business people and the Government to ensure that the latter benefits from independent and expert advice when deciding its own research priorities.

The Government's Strategy

Realising Our Potential was the first major policy review on science for over 20 years.

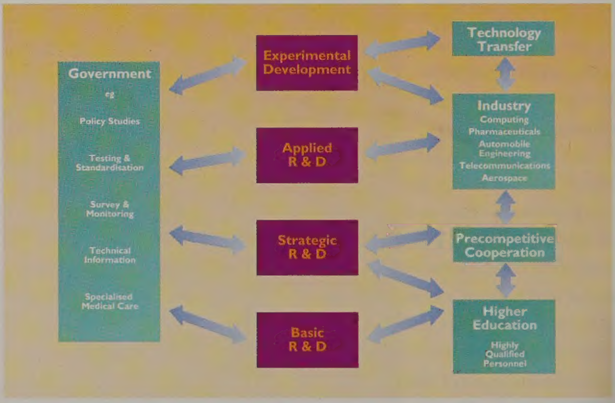
It outlines the Government's strategy to improve Britain's competitiveness and quality of life by maintaining the excellence of science, engineering and technology in Britain.

This will be done by:

- developing stronger partnerships with and between the science and engineering communities, industry, research charities and other research organisations, leading to Britain's enhanced wealth creation;
- supporting the science and engineering base to advance knowledge, increase understanding and produce highly educated and trained people;
- contributing to international research efforts, particularly European research;
- continuing to promote the public understanding of science, technology and engineering and their role in the economy;
- ensuring the efficiency and effectiveness of government-funded research.

A new Technology Foresight Programme, intended to strengthen links between industry, academia and government, is being established. It will influence private sector strategies; inform the work of the Council for Science and Technology, the research councils, the higher education funding councils and government departments.

Figure 1:
Science and technology, research and development, innovation and wealth creation.



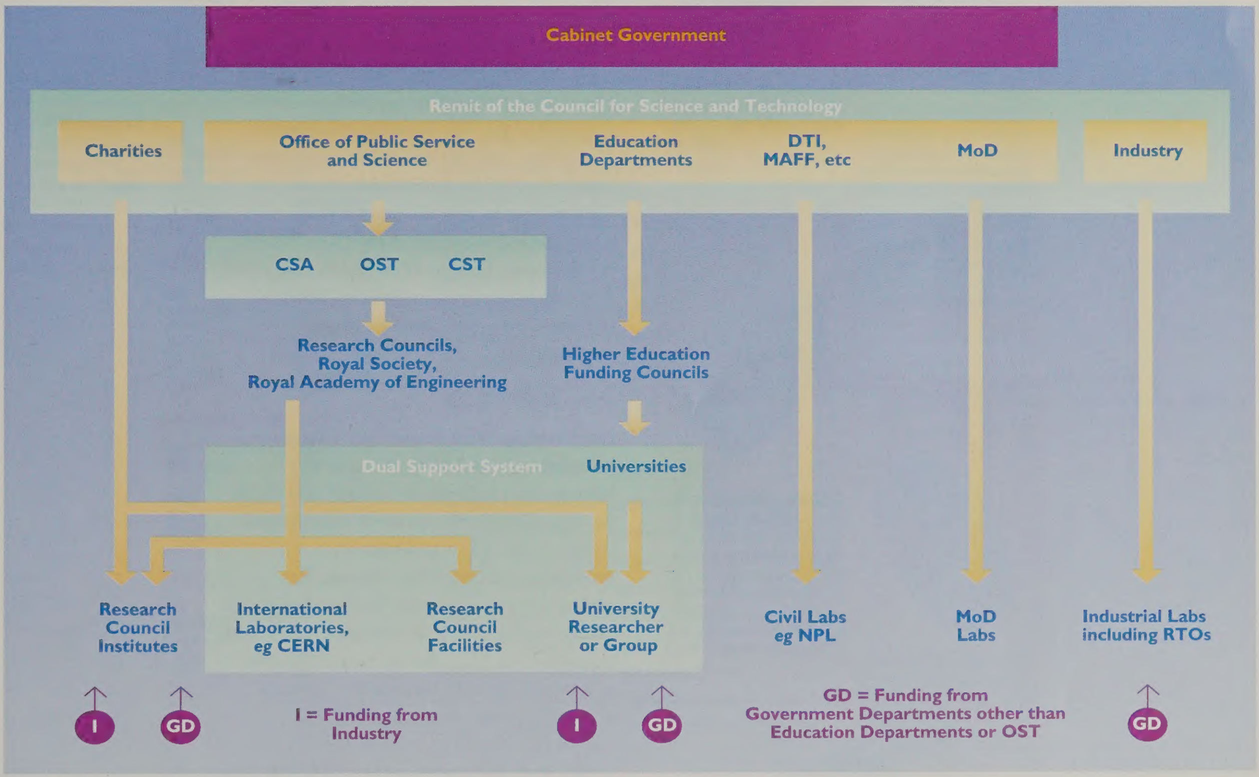
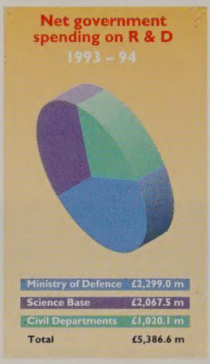

Cabinet Government
Remit of the Council for Science and Technology
Charities
Office of Public Service and Science
Education Departments
DTI, MAFF, etc
MoD
Industry
CSA
OST
CST
Research Councils, Royal Society, Royal Academy of Engineering
Higher Education Funding Councils
Dual Support System
Universities
Research Council Institutes
International Laboratories, eg CERN
Research Council Facilities
University Researcher or Group
Civil Labs eg NPL
MoD Labs
Industrial Labs including RTOs
I
GD
I = Funding from Industry
I
GD
GD = Funding from Government Departments other than Education Departments or OST
GD

Figure 2:
The organisation of research in Britain.

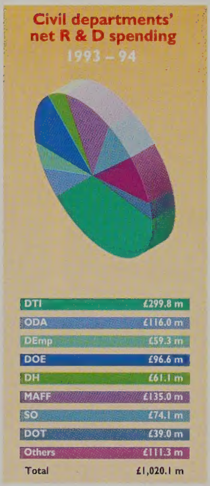
Diagnosing with DNA:
DNA probe tests promise to provide sensitive and selective detection of bacteria and viruses in hours. The biotechnologist shown here is working at PA Consulting Group's laboratory near Cambridge on a project to automate a DNA test – something that could make it a simple 'one-step' operation.
The company, which has a worldwide network of 20 offices and 2,300 staff, is playing a leading role in the development of DNA probes.

Figure 3:
Net government spending on R & D 1993 – 94.



Ministry of Defence	£2,299.0 m
Science Base	£2,067.5 m
Civil Departments	£1,020.1 m
Total	£5,386.6 m

Figure 4:
Civil departments' net R & D spending 1993 – 94.



DTI	£299.8 m
ODA	£116.0 m
DEmp	£59.3 m
DOE	£96.6 m
DH	£61.1 m
MAFF	£135.0 m
SO	£74.1 m
DOT	£39.0 m
Others	£111.3 m
Total	£1,020.1 m

Research and Development Spending

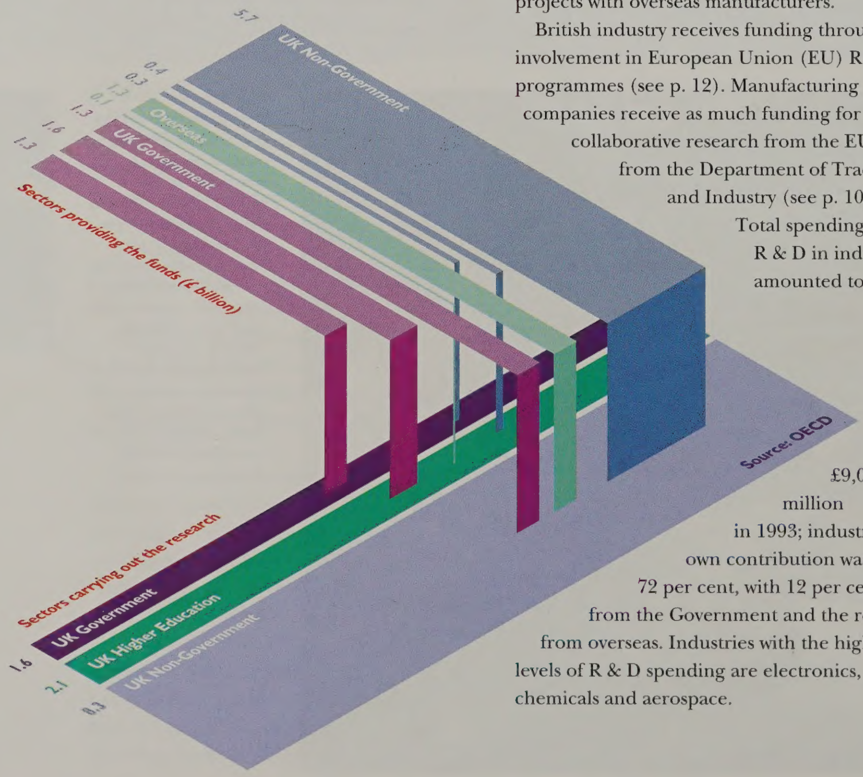
Total spending in Britain on scientific research and development (R & D) in 1993 was £13,752 million – just over 2 per cent of gross domestic product. Industry provided over half of this, the Government around 33 per cent, and the remainder came from charities, trusts and overseas sources.

Britain ranks seventh out of the 24 industrialised countries of the Organisation for Economic Co-operation and Development (OECD) in the amount spent on R & D in proportion to gross domestic product (see Figure 6).

Industrial R & D

Many companies in major industries finance their own research and run their own laboratories. Industry also contributes to the funding of university research and finances contract research at government establishments and other research and technology organisations. Smaller companies commission research from industrial research organisations. Many British companies take part in commercial co-operative research projects with overseas manufacturers.

British industry receives funding through involvement in European Union (EU) R & D programmes (see p. 12). Manufacturing companies receive as much funding for collaborative research from the EU as from the Department of Trade and Industry (see p. 10). Total spending on R & D in industry amounted to £9,070 million in 1993; industry's own contribution was 72 per cent, with 12 per cent from the Government and the rest from overseas. Industries with the highest levels of R & D spending are electronics, chemicals and aerospace.



Source: OECD

Figure 5:
Relationship between sources of funding and performers of research and development 1991.

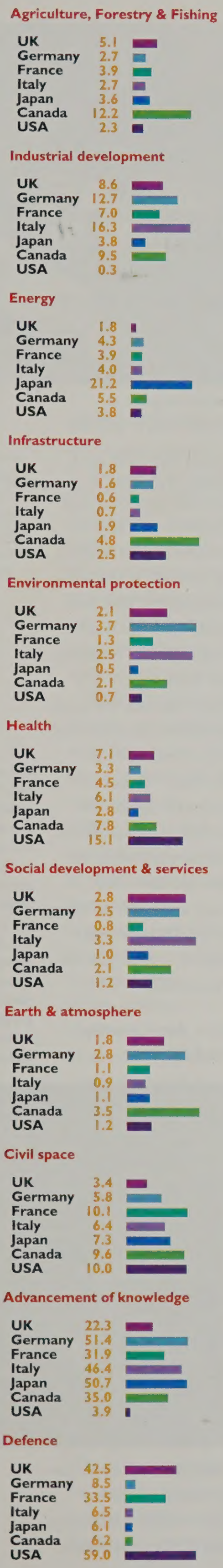


Figure 6: How the British Government's percentage distribution spending on R & D compared with other OECD countries in 1993. The data for Canada are for 1992. Data for 1993 were unavailable at the time of compilation.

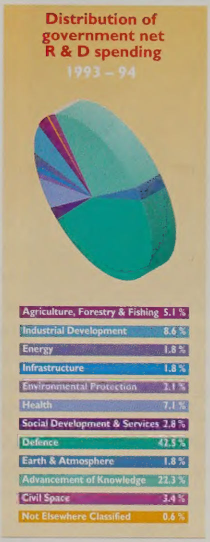


Figure 7: Distribution of government net R & D spending 1993 – 94.

Government-funded R & D

Government finance for R & D goes to research establishments, institutions of higher education and private industry, as well as to collaborative research programmes. Among government departments, the Ministry of Defence (MoD) has the largest research budget (see p. 10). The main civil departments involved are the Department of Trade and Industry (DTI – see p. 10), the Ministry of Agriculture, Fisheries and Food (MAFF) and the Department of the Environment (see Figure 4).

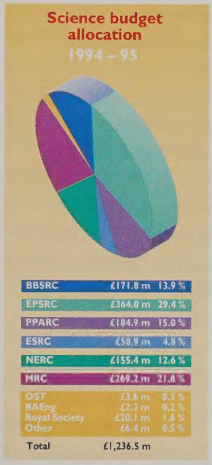


Figure 8: Science budget allocation 1994 – 95.

Funding by Medical Research Charities and Others

Medical research charities provide a major source of funds for biomedical research in Britain. They range from the Wellcome Trust, the world's largest medical charity, and the Imperial Cancer Research Fund, Europe's largest independent cancer research institute, to small charities dedicated to raising funds for work in very rare disorders. Their combined contribution in 1992 – 93 was around £317 million (see table).

Principally, charities support biomedical research in institutions which are mainly funded by others.

The Association of the British Pharmaceutical Industry is a trade association representing over 100 manufacturers of prescription medicines. Much of the £1,400 million spent by these manufacturers on so-called in-house research includes allocations to universities/hospital departments for clinical evaluation of potential new medicines.

Spending in Britain by leading medical research charities 1992 – 93

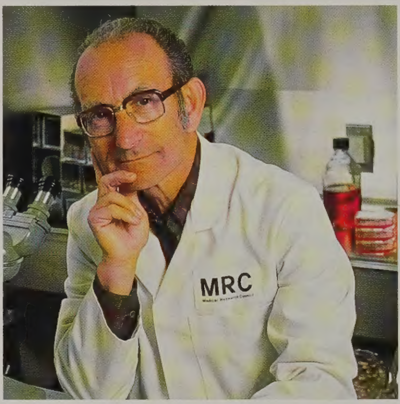
Charity	£ million
Wellcome Trust	*77.2*
Imperial Cancer Research Fund	*49.9*
Cancer Research Campaign	*44.2*
British Heart Foundation	*20.9*
Arthritis and Rheumatism Council	*11.8*
Leukæmia Research Fund	*9.1*
Yorkshire Cancer Research Campaign	*4.8*
Multiple Sclerosis Society	*4.7*
Ludwig Institute for Cancer Research	*4.5*
Action Research	*3.5*

Organisation and Funding

Research Councils

The research councils support research, study and training in universities and other higher education establishments, their own institutes, and international research centres. Funded chiefly from the OST, they also receive income from research commissioned by government departments and from the private sector. Each council is an autonomous body, with members of its governing council drawn from the universities, professions, industry and the Government.

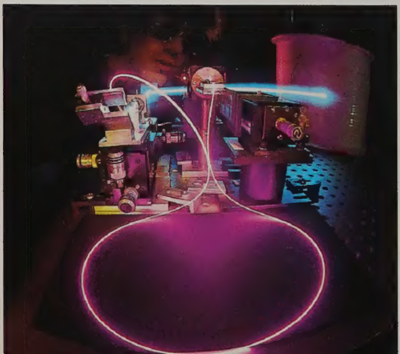
All the councils have 'mission statements' with commitments to enhancing industrial competitiveness and the quality of life while maintaining support for basic research. Their governing councils include part-time chairmen, chosen to bring industrial and commercial experience.



César Milstein, whose work in basic science has produced a new tool for applied medicine of enormous importance: monoclonal antibodies. By fusing an antibody-producing cell with a cancer cell, he and his colleague Köhler produced a cell that could reproduce indefinitely. These cells are now used widely in medicine and biological research.

The Engineering and Physical Sciences Research Council (EPSRC)

The EPSRC has been given a mission by government to stimulate, facilitate and manage research skills and development in engineering and the physical sciences, for the benefit of industry in Britain and the research base. The Council supports research and training in core disciplines of science and engineering (such as chemistry, physics, mathematics, electrical and mechanical engineering) and in generic technologies such as materials science, information technology and computer science, design and integrated production, control and instrumentation, and clean technology. The user industries of the Council include the electronic and electrical industries, communications, construction, transport, pharmaceuticals and the chemical industries.



A researcher at Southampton University takes a probing look into the behaviour of a blue light laser which promises far-reaching advances in information storage and medical diagnosis. He is shown with an experimental rig supporting a Ytterbium doped silica glass optical fibre developed entirely by the Optoelectronics Research Centre (ORC), which receives support from the Engineering and Physical Sciences Research Council (EPSRC).

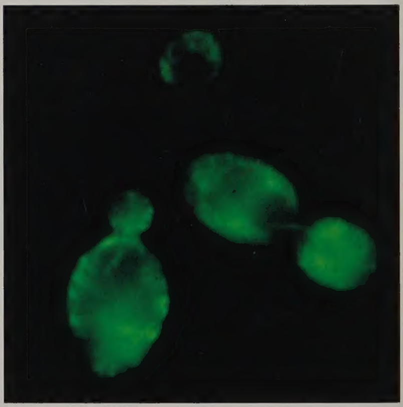
The Council for the Central Laboratory of the Research Councils (CCL)

The CCL promotes high-quality scientific and engineering research by providing facilities and technical expertise to meet the needs of the other research councils and their user communities. It is responsible for two research establishments: the Rutherford Appleton Laboratory at Chilton in Oxfordshire, and the Daresbury Laboratory near Warrington, Cheshire. These centres of special research provide experimental facilities too large or complex to be housed by individual academic institutions; they also undertake contract research. For example, the Rutherford Appleton has the most powerful laser devoted to civil research in Europe – Vulcan – which is capable of simulating conditions inside stars, while its ISIS facility – the world's most powerful pulsed source of neutrons and muons – is used by some 2,000 scientists from more than 20 countries to investigate the microscopic properties of materials.

The Particle Physics and Astronomy Research Council (PPARC)

The PPARC covers particle physics; astronomy and astrophysics; and solar system science. The aim is to understand the structure of the physical world, and the forces that govern its behaviour, from the cosmic to the sub-nuclear scale.

The Council provides Britain's researchers with access to the necessary facilities through international partnerships, the Royal Observatories, with sites in Britain and overseas, and national facilities,



In a collaborative project with British Biotech plc, researchers at Manchester University have produced and used monoclonal antibodies to map the external surface epitopes of the virus-like particle of the yeast retrotransposon, Ty1. British Biotech plc are engineering the physical characteristics of the particle to form a novel antigen presentation system (vaccine) for diseases including AIDS.

The nuclear magnetic resonance (NMR) spectrometer installed at the MRC's Radiobiology Unit in Oxford. NMR spectroscopy developed initially from an esoteric branch of physics into what is now an indispensable tool for chemists.

such as MERLIN, run by the Nuffield Radio Astronomy Laboratory at Jodrell Bank. Some facilities are provided by the Rutherford Appleton Laboratory for Britain's particle physics and space science programmes.

The Biotechnology and Biological Sciences Research Council (BBSRC)

The BBSRC's scientific themes are biomolecular sciences; genes and developmental biology; biochemistry and cell biology; plant and microbial sciences; animal sciences and psychology; and engineering and physical sciences. Strategic programmes are directed at agricultural systems; chemicals; and food.

BBSRC's core scientific programmes in biology, and related areas in chemistry, physics and engineering, comprise both basic and strategic research. More applied research is undertaken in collaboration with, and full funding by, industrial and governmental partners. Users and beneficiaries include the agriculture, bioprocessing, chemical, food, healthcare, pharmaceutical and other biotechnological related industries.

Research is supported in research institutes and interdisciplinary research centres, as well as in groups and units in universities.

Medical Research Council (MRC)

The MRC is the main government agency supporting medical research. The Council supports research in its own establishments and through its grant systems to research workers at higher education institutions and hospitals. The MRC's largest research establishments are the National Institute for Medical Research in London and the Laboratory of Molecular Biology at Cambridge. The MRC has recently launched a new clinical research initiative, of which the newly created Clinical Sciences Centre at the Royal Postgraduate Medical School, London, is a major component.

A short pulsar of laser light from the Satellite Laser Ranger at the Royal Greenwich Observatory is used to determine the range of a satellite as it moves around the earth. Developed jointly by the Observatory and by Hull University, the equipment can work both by day and by night and is among the most accurate systems in the world.

Research centres have been established in molecular medicine, protein engineering, cell biology, brain activity and human behaviour, brain repair, and toxicology.

Natural Environment Research Council (NERC)

NERC is Britain's leading body for research, survey, monitoring and training in the environmental sciences. The Council funds the highest quality science in universities and its own network of laboratories. It provides a range of facilities for the environmental science community, including a fleet of research vessels. NERC also undertakes research paid for by public and private sector bodies worldwide, including overseas governments.

NERC'S research laboratories are grouped to form the British Antarctic Survey, the British Geological Survey, the Centre for Coastal and Marine Sciences, the Centre for Ecology and Hydrology and the Southampton Oceanography Centre.

Scuba diving in the Bellingshausen Sea: NERC-supported scientists at work on a study of the role of the Southern Ocean in shaping the global environment. The study is part of the British participation in the international Joint Global Ocean Flux Study (JGOFS).

Economic and Social Research Council (ESRC)

The ESRC is Britain's leading research agency for the social sciences, supporting social science research in British higher education institutions and independent research institutes; by investing in the training of social scientists; and by developing and improving research methods and data sources.

Subject areas supported by the Council include economics, education, human development, environment and planning, industry, information technology, management, politics, psychology and sociology.

Research Financed by Government Departments

Government support for research in industry is led by the DTI, together with the Welsh, Scottish and Northern Ireland industry departments. The departments' main role is to stimulate innovation in industry so as to enhance competitiveness in Britain and overseas.

The DTI runs a number of collaborative research programmes aimed at stimulating innovation (that is the successful exploitation of new ideas) in industry and encouraging the successful transfer of inventions, techniques and knowledge from research to industry.

The DTI is concentrating more of its support on improving companies' access to, and use of, technology and on encouraging better innovation practice in industry and is concerned that this should be demand-led and locally delivered wherever practicable.

In 1993 – 94 the DTI spent £299.8 million on R & D, covering general industrial innovation, aeronautics, space, nuclear and non-nuclear energy and support for statutory, regulatory and policy responsibilities. A further £101.1 million was allocated to technology transfer, best practice and related activities.

The government department with the largest research budget is the MoD, which spent more than £2,299 million on R & D in 1993 – 94. The MoD's Defence Research Agency (the largest scientific employer in Britain) sub-contracts research to industry and universities, ensuring that their know-how is harnessed in meeting military requirements. It also works closely with industry in order to ensure that scientific and technological advances are taken forward at an early stage into development and production.

This technology transfer is not confined just to the defence industry but has also led to important 'spin-offs' from defence into civil markets, in fields ranging from new materials and electronic devices to avionics and advanced aircraft materials.

The Government is committed to achieving a gradual reduction in real terms in spending on defence R & D in future years.

Researchers examine a computer aided design molecular model of the DNA reverse transcriptase enzyme. The enzyme (green) is seen interacting with and building a double-stranded DNA molecule (red, blue). Reverse transcriptase is an enzyme contained in certain RNA viruses. When the virus infects an animal cell, the enzyme builds double-stranded DNA molecules from the single-stranded RNA templates. Viruses with this ability are called retroviruses. Research into reverse transcriptase activity could prevent retroviral infection.

Other Government Departments

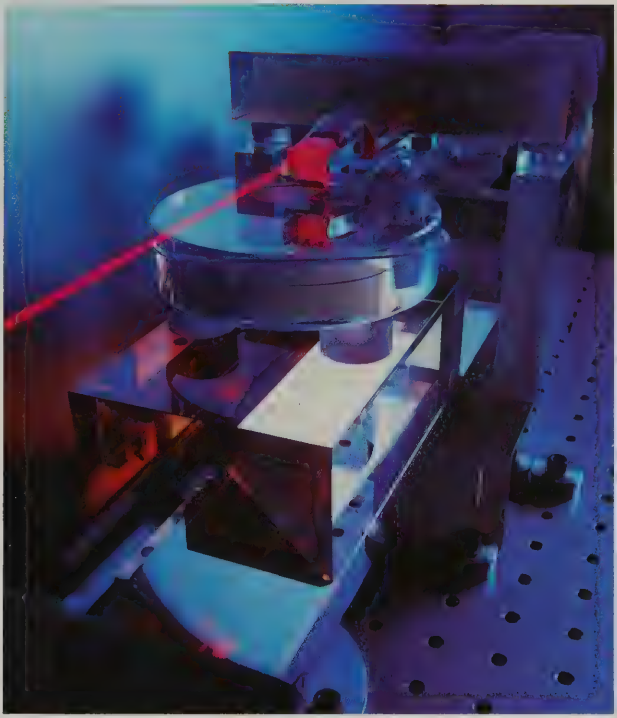
Other government departments (along with their counterparts in Wales, Scotland and Northern Ireland – see Figure 4) which have substantial R & D programmes include:

- MAFF;
- the Department of the Environment;
- the Department of Health; and
- the Overseas Development Administration, which conducts research programmes directly targeted at the main needs of developing countries.

Research in Universities

About 40 per cent of research carried out in universities in Great Britain is financed by the Higher Education Funding Councils. The other main channels of support for scientific research in universities are the research councils, government departments, charities, industry and the EU. Universities are expected to recover the full cost of short-term commissioned research from the Government and industry.

The high quality of research in universities, and their marketing skills, have enabled them to attract more funding from a large range of external sources, in particular from industry. There is growing co-operation between the universities, industry and the Government in joint projects. The research income of universities from industry and other outside sources is rising rapidly and in 1992 amounted to £110 million. Most British universities have industrial liaison officers, whose role is to identify research within their institutions with commercial potential.



Nanosurf 3 is a laser stylus profilometer used for nanometric surface topography measurement, in which the stylus follows the undulations of the surface and an interferometer measures the displacement of the stylus. There are increasing demands on industry for new capabilities in machining, positioning and control, in some cases down to dimensions commensurate with the atom. Nanometrology covers the range of measurement from 0.1 nm to 100 nm (10^{-10} m to 10^{-7} m).

While most industrial R & D is financed by industry itself, the Government runs a number of schemes to encourage closer contacts and exchanges of ideas and skills between the science base and industry, leading to Britain's wealth creation.

LINK, administered by the OST, is a scheme which involves most government departments and the research councils funding major R & D programmes. It encourages collaboration on high-quality, industrially relevant research between industry and higher education institutions and research bodies. LINK is designed to help bridge the gap between industry and the research base for the benefit of the British economy. The Government funds up to 50 per cent of costs and industry the rest.

By the end of 1993, 35 LINK programmes had been announced, worth a total of £430 million. Each programme supports a series of projects and every project involves at least one research partner and one industrial partner.

A wide range of technology transfer initiatives are supported by the OST through the research councils, which collaborate with industry through joint research programmes, by providing trained people and by entering into joint royalty and profit-sharing agreements with industry and technology transfer companies.

Science Parks

Science parks involve many partnerships between higher education institutions and industry to promote commercially focused research, often involving advanced technology. By mid-1993 there were 40 such parks, at or near universities, accommodating over 1,000 companies. Most are involved in computing, electronics, instrumentation, robotics, electrical engineering, chemicals and biotechnology.

The research councils have established some 20 interdisciplinary research centres to encourage collaboration with industry and business in key technologies and have formed companies to exploit the potential of their research. For example, the MRC Collaborative Centre undertakes collaborative research projects supported by industry to develop applications of the fundamental scientific work of its units leading towards new medical products and practices. The MRC has also set up a number of companies to exploit the potential of its research findings.

A growing number of universities now offer industry interdisciplinary research centres with exploitable resources. These include access to analytical equipment, library facilities and worldwide databases as well as academic expertise.

Industrial Research and Technology Organisations

Research and Technology Organisations (RTOs) are independent organisations carrying out commercially relevant contract research and other services on behalf of industry, in many cases for specific sectors of industry. Britain has the largest RTO sector in Europe, consisting of approximately 70 organisations, with staff of over 10,000.

These research organisations conduct confidential strategic research which companies need for their next generation of products or services. They may develop new products and carry out routine testing, particularly relevant to small companies which may not be able to afford the advanced instruments needed to make detailed measurements. By spreading the cost of development over a large number of customers, they can assemble impressive arrays of instrumentation, such as an advanced laser microscope recently developed by a research association for a food company.

Organisation and Funding

International Collaboration

Telescope domes at the summit of the Mauna Kea volcano in Hawaii, one of the world's best sites for astronomical observations. The 15 m James Clerk Maxwell telescope is at the far right on the near ridge.

Britain plays a key role in a wide range of major international scientific facilities and research programmes.

European Union

Britain is engaged in extensive programmes run by the EU to strengthen the scientific and technological basis of European industry and improve its international competitiveness. The EU's Fourth Framework Programme, lasting from 1994 to 1998, has a budget of £9,500 million.

Britain has helped to secure agreement that the EU should develop 'generic' technologies with a wide range of industrial applications, rather than fund research projects to meet the needs of specific industrial sectors. The EU has also agreed that more resources be devoted to disseminating technology from research projects to small and medium-sized enterprises.

Britain is involved in many different aspects of the Framework Programme. Among recent successful collaborations:

- The Joint European Torus nuclear fusion project (JET), based at Culham, Oxfordshire, demonstrated the first controlled release of fusion power in 1991 (see p. 23). Members of JET include all EU countries and Switzerland.
- Programme EVA (European Vaccination Against AIDS), whose centralised facility is based in Britain, provides the necessary reagents for AIDS vaccine research and helps to co-ordinate collaborative research projects within Europe and beyond. The Programme's management group consists of scientists from 10 European countries.
- A project led by the Marine Technology Centre at Glasgow University, with researchers from Italy, the Netherlands, France and Britain, is examining how to protect oceanographic sensors from being fouled by bacteria and microalgae.
- The MOSAIC project, involving France, Germany and Britain, aims to develop high performance optoelectronic devices for high capacity optical fibre-based information technology and communication systems.

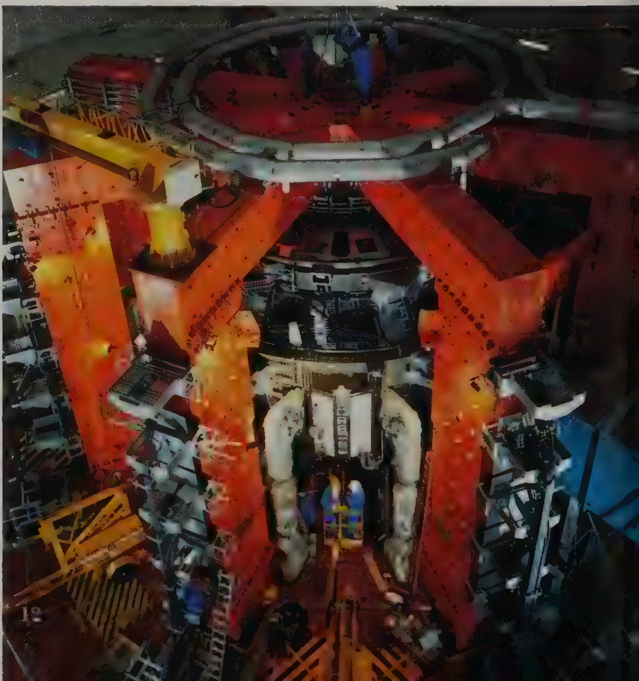
Other International Activities

- Over 500 British organisations participate in EUREKA, an industry-led scheme to encourage European co-operation in developing and producing advanced technology products with worldwide sales potential. Britain is currently involved in 257 projects. Major projects include research into a European standard for high-definition television and into semi-conductors.
- The COST (European Co-operation in the Field of Scientific and Technical Research) programme encourages the co-operation of national research activities across Europe, with participants coming from industry, academia and research laboratories. Transport, telecommunications and materials have traditionally been the largest areas supported. New areas include neuroscience, agriculture and biotechnology, and forests and forestry products. Britain is an active participant in COST.

The research councils continue to build close and mutually beneficial links with the major scientific nations though liaison with key organisations and, where appropriate, drawing up of agreements which strengthen support for scientist-to-scientist links and facilitate policy discussions. For example, BBSRC has agreements with its counterpart organisations in France, the Netherlands, Japan and Korea.

Through the PPARC, Britain contributes towards CERN in Geneva (see p. 23), the European Space Agency (ESA) and EISCAT, which conducts research on the ionosphere. Britain contributes, through the EPSRC, to the high-flux neutron source at the *Institut Laue-Langevin* and to the *European Synchrotron Radiation Facility*, both at Grenoble.

Britain also participates in the *European*



The JET Tokamak during the final stages of construction.

The Channel Tunnel system, joining Britain with France and opened in 1994, is the longest submarine tunnel in the world and is undoubtedly the most complex in structure.

Molecular Biology Laboratory (EMBL), based in Heidelberg, Germany, and has been chosen as the location for the European Bioinformatics Institute, an outstation of the EMBL. The Cambridge-based Institute provides up-to-date information on molecular biology and genome sequencing for researchers throughout Europe.

The MRC pays Britain's contribution to the *Human Frontier Science Program*, on behalf of all the research councils. The Program supports international collaborative research into neuroscience and molecular biology.

The NERC's James Rennell Centre in Southampton is a focal point for Britain's contributions to the *World Ocean Circulation Experiment*, one of the major components of the World Climate Research Programme. In 1993 Britain was chosen as the location for the scientific planning office of the *Ocean Drilling Program's* (ODP – see p. 46) Joint Oceanographic Institute for Deep Earth Sampling.

Britain is a member of the science and technology committees of international organisations such as OECD, the North Atlantic Treaty Organisation (NATO), and various specialised agencies of the United Nations.

Among non-governmental organisations, the research councils, the Royal Society and the British Academy were founder members of the *European Science Foundation* in 1974 and play a full part in its activities.

The British Council, which works in 228 towns and cities in 109 countries, promotes educational, cultural, scientific and technological collaboration between Britain and other countries. The Council works closely with the British scientific community, promoting British expertise by supporting partnerships in science and medicine; promoting links and joint research collaboration and training; supporting overseas development, particularly human resource and institutional development; providing information on British research, education and training services; and demonstrating the excellence of British science, technology and engineering.

The research councils also maintain, with the British Council, a joint office in Brussels – the UK Research and Higher Education European Office – to promote European co-operation in research. Staff in British Embassies and High Commissions promote contacts in science and technology between Britain and overseas countries.

Learned Societies

More than 300 learned societies promote science and technology through meetings, lectures, publications and sponsorship.

- *The Royal Society*, founded in 1660, is Britain's national academy of sciences, many of whose members serve on governmental advisory councils and committees concerned with research. The Society is involved in a variety of international scientific programmes and facilitates collaborative projects and the exchange of scientists through bilateral agreements with academies and research councils throughout the world. Nearly 80 per cent of funding comes from the Government and the rest from private sources.
- *The Royal Academy of Engineering*, founded in 1976, is the national academy of engineering in Britain, promoting the advancement of support engineering for the benefit of the public. It administers a grant from the OST, which accounts for less than 30 per cent of its total budget.

British Participation in Major International Collaborations

EC Framework Programmes
European Science Foundation
European Co-operation in the Field of Scientific and Technical Research (COST)
All research councils

European Molecular Biology Laboratory and Conference
International Agency for Research on Cancer
Human Frontier Science Program **MRC**

World Climate Research Programme
Ocean Drilling Program
International Geosphere-Biosphere Programme **NERC**

Institut Laue-Langevin
European Synchrotron Radiation Facility **EPSRC**

European Space Agency (ESA)
Anglo-Australian Observatory
Isaac Newton Group of Telescopes (La Palma)
James Clerk Maxwell Telescope (Hawaii)
GEMINI (optical/infrared astronomy)
European Laboratory for Particle Physics (CERN)
Hadron Electron Ring Accelerator (HERA)
European Incoherent Scatter Radar Facility (EISCAT) **PPARC**

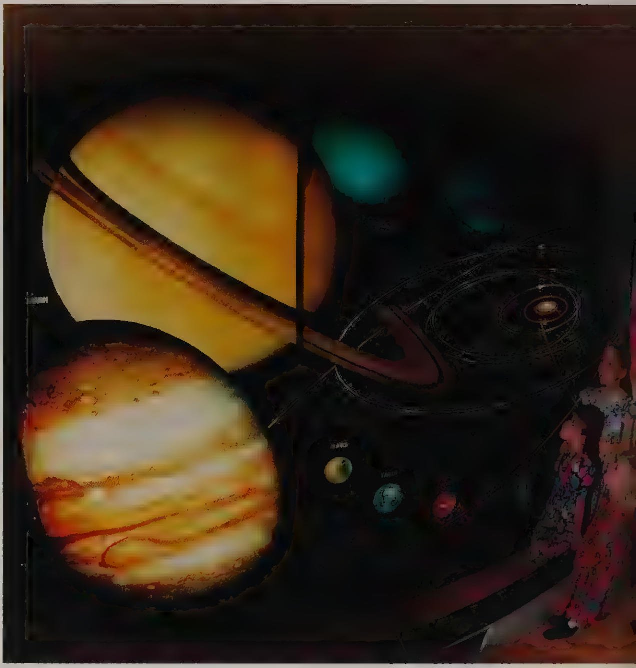
ISIS (pulsed neutron source)
Synchrotron Radiation Source **CCL**

Promoting Public Awareness

Although public interest in scientific issues is growing, there is also a lack of non-specialist information about scientific and technological activity. By improving the climate for innovation and providing companies with access to technology and best practice, the Government hopes that industry itself will facilitate the change towards a better understanding and exploitation of the benefits of science, engineering and technology.

Several long-established organisations in Britain work to improve the understanding and communication of science – such as the Royal Society (see p. 13) and the Royal Institution (see below). They publicise scientific developments through lectures and publications for specialists and for schoolchildren. They also hold press conferences to provide media representatives and correspondents with a steady flow of information about scientific developments. For example:

- *The Royal Institution*, founded in 1799 as a scientific research centre and now running its own research laboratories, provides annual televised Christmas lectures.
- *The British Association for the Advancement of Science (BAAS)*, founded in 1831, holds an annual Festival of Science, attended by scientists and interested laypeople; the festival presents papers on the latest scientific advances and receives widespread press coverage.



The Committee on the Public Understanding of Science (COPUS), set up in 1986 by the Royal Society, the BAAS, and the Royal Institution, acts as a focus for a broad-ranging programme of activities in Britain to improve

The Palm House at the Royal Botanic Gardens, Kew. This gigantic greenhouse contains groves of palms, vines and thickets of giant bamboos and bananas – a microcosm of the rainforests of the Americas, Africa and Asia, currently the most threatened habitats in the world.

Young visitors at the Old Royal Observatory at Greenwich, London, scrutinising a brightly illuminated wall panel of the heavens. Visitors can unravel some of the mysteries of time and space by using a series of hands-on high-tech machines, and by examining the world's finest collection of precision clocks and scientific instruments.

public awareness of science and technology. The annual COPUS Science Book Prize is awarded to authors of non-specialist books.

National Campaign

The Government's recent education and training reforms include measures to ensure a more scientifically and technologically informed population. To complement these, the Government believes that there is a need for a national campaign to increase the general level of understanding of science and technology issues throughout society. It has agreed to work closely with key charitable organisations to promote the campaign.

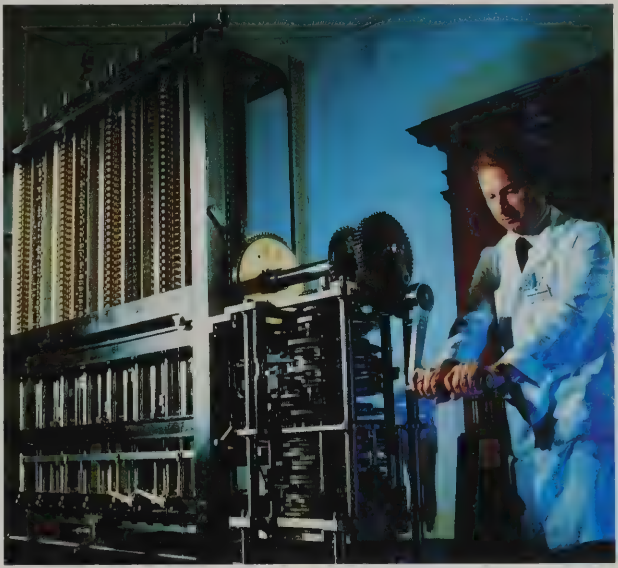
Scientific Museums

The Science Museum in London has an extensive collection of scientific instruments and machinery, complemented by interactive computer games and audio-visual equipment for visitors to use. In this way the Museum explains scientific principles to the public and documents the history of science, from early discoveries to space age technology.

The Natural History Museum, which includes the Geological Museum, in London, is one of the world's principal centres for research into natural history, offering an advisory service to institutions all over the world.

Other important collections are held by the Museums of Science and Industry in Birmingham and in Manchester, the Museum of the History of Science in Oxford, the Royal Scottish Museum, Edinburgh, and the Royal Botanic Gardens at Kew and Edinburgh.

A reconstruction, at the Science Museum, of a computer designed between 1847 – 49 by Charles Babbage, widely regarded as the first computer pioneer.



Big Science

A LARGE NUMBER of scientific advances are being achieved in Britain's laboratories today: in the limited scope of this booklet only a few of the wide range of research projects recently completed or currently in progress in Britain's universities, research institutes and industry can be highlighted.

Britain's participation in research in large-scale scientific facilities in astronomy, high-energy physics and planetary science – the so-called 'big' sciences – is carried out through international collaboration, with countries joining together to build increasingly sophisticated and expensive large-scale facilities such as particle accelerators (for high energy physics), ground- and satellite-based instrumentation (for astronomy and space science) and tokamaks (large magnetic machines for nuclear fusion experiments).

Astronomy

Britain has a distinguished tradition in astronomy stretching back over 300 years to the pioneering work of cataloguing star positions for maritime navigation. Today, however, the central theme is not where objects are but what they are.

Astronomy and astrophysics concentrate on understanding how stars and galaxies formed and have evolved, and on working back to characteristics of the 'big bang', as well as testing the laws of physics under conditions totally inaccessible to laboratory experiments. Britain remains at the forefront of this research, a major reason being the continued development of excellent and innovative instruments. Exciting discoveries have been made by British scientists using the combination of facilities available to them.

Recent Astronomical Discoveries

The brightest known object in the universe, believed to be a violently active galaxy, was discovered in 1991 by astronomers from Cambridge University. A special machine was used to measure photographs taken from the UK Schmidt Telescope in Australia. This is the second most distant known object in the universe, but much brighter than the others – being 10,000 times more luminous than the Milky Way galaxy – and 300 million million times more luminous than the sun.

A new X-ray star was discovered in 1989, with a space-borne instrument invented at Leicester University. It was later observed to be an ordinary low-mass star (less massive than the sun) orbiting and losing mass to a compact companion object – possibly a black hole. The known star was observed in summer 1991 on the William Herschel Telescope, La Palma, with spectacular results: the astronomers discovered features that could be attributed to the secondary, companion star of a minimum mass of over six solar masses – six times the mass of the sun. However, its actual mass is thought to be much higher within the parameters of a double star system – and hence the best candidate for a stellar-size black hole known.

The James Clerk Maxwell radio telescope on Mauna Kea, Hawaii.

The PPARC is the principal partner in the international La Palma Observatory in the Canary Islands. The Observatory's four telescopes include the 4.2-metre William Herschel, the third largest single-mirror optical telescope in the world. On Mauna Kea, Hawaii, the PPARC has a 3.8-metre infra-red telescope, the largest telescope in the world designed specifically for infra-red observations, and the 15-metre James Clerk Maxwell radio telescope (built in collaboration with the Netherlands and Canada).

In 1992, using a new detector on the

A visualisation of a black hole, simulating gravitational waves emitted by a disturbed black hole which is beginning to return to an equilibrium state. The colour and height of each point represents aspects of the gravitational wave fields. The black line near the centre is the apparent surface of the black hole. As the black hole seeks its equilibrium state, it emits characteristic gravitational waves. Visualisation by NCSA, University of Illinois.

Mauna Kea infra-red telescope, a team of British and US astronomers discovered a rare form of hydrogen H_3^+, associated with aurorae around the polar regions of Saturn. Monitoring the strength of the H_3^+ radiation may provide information on the interaction of the planet with wind particles from the sun.

Through the PPARC Britain is taking part in one of the decade's most important ground-based astronomical projects – Gemini, an international collaboration to build two 8-metre telescopes that will give all-sky coverage from sites in Hawaii and Chile.

Black Holes

Black holes are collapsed stars where gravity is so strong that light cannot escape. To find black holes, astronomers look at binary systems in which a star less massive than the sun is losing material to a companion neutron star or black hole.

In 1993, using new infra-red technology, astronomers at Keele and Oxford Universities 'weighed' the compact stellar object in an X-ray binary (double-star) system and found it to be a black hole of 16 solar masses.

The British astronomers developed a new method of determining the mass of compact stars in these binary systems.

These new observations make it possible to determine the mass of the compact star with a considerable amount of confidence. The astronomers believe the identification of black holes is no longer in doubt and that it will now be possible to study them and their influence on their surroundings in some detail.

Radio astronomy telescopes based in Britain complement the work of British optical, infra-red and millimetre wave telescopes on overseas sites as well as the British and ESA space programmes. Manchester University's Nuffield Radio Astronomy Laboratory at Jodrell Bank (see box above) is one of the world's leading centres for radio astronomy.

Jodrell Bank

Astronomy at Jodrell Bank began in 1945, when Bernard Lovell installed some government surplus, ex-military radar equipment at Manchester University's botanical research station in Cheshire.

The earliest work at Jodrell Bank was the study of meteors by using radar techniques developed during the Second World War. This led to the discovery of new meteor streams and their identification with debris spread around the orbits of comets. The radar work confirmed that all meteors were members of the solar system.

Once the principles of radio astronomy were established, Bernard Lovell and his colleagues gradually shifted their attention from meteors to cosmic radio waves coming from the Milky Way and beyond. This work grew to dominate the activities at Jodrell Bank, and helped to establish radio astronomy as a revolutionary method of investigating the universe.

During the first dozen years of Jodrell Bank's existence, great effort was directed to the building of highly sensitive radio equipment, resulting in the completion of the Mark 1 telescope in 1957. Designed by the Sheffield engineer Charles Husband, the telescope has a solid steel bowl 76 metres in diameter and is steerable to any point in the sky. The telescope, now known as the Lovell telescope, ranks as one of the most powerful radio telescopes in the world, making vital contributions to solving many astronomical problems.

Astronomer Bernard Lovell (born 1913) in the control room of the radio observatory which he founded and made famous at Jodrell Bank, near Manchester. Lovell worked on cosmic ray studies before the Second World War, when he helped to develop radar.

Big Science

Two key instruments on ENVISAT-1:

- the advanced synthetic aperture radar (ASAR), which will make either large-scale, broad-swathe images or high-resolution, detailed images; and
- the Michelson Interferometer for Passive Atmospheric Sounding (MIPAS), which will be able to detect and measure a wide range of photo-chemically interrelated trace gases in the atmosphere, including ozone and methane.

Space Science

While ground-based telescopes can probe the universe in the visible, infra-red and radio regions of the spectrum, the need to get the full picture of the hugely diverse events taking place in stars and galaxies requires sensitive probes to be launched above the Earth's atmosphere. The far infra-red, ultraviolet, and X-ray wavelengths can be observed only from space. British laboratories and companies have a long history of success in the design and construction of special instruments for satellites.

Space Activities

Britain's support for civil space research is co-ordinated by the British National Space Centre (BNSC), a partnership between various government departments and research councils. The BNSC encourages industry to exploit opportunities in space, based on appraisal of project costs and potential technological and commercial benefits. Through the BNSC, Britain spent some £170 million on space activities in 1992 – 93. More than half of this was devoted to programmes shared with the ESA.
The remainder supported research and development in government establishments, universities and industry.

Earth Observation (Remote Sensing)

A key element of Britain's space programme is Earth observation (satellite remote sensing). Remote sensing involves using instruments mounted on satellites and aeroplanes to study the Earth's land, sea, ice and atmosphere from space. It has considerable commercial potential, including mapping, crop monitoring (see below), oil and mineral exploration, fisheries, weather forecasting and monitoring iceberg movements.

Britain has committed around £60 million to the ESA's European Remote Sensing satellite (ERS-1) programme, which was launched in 1991 and provides all-weather, 24-hour coverage of the Earth. Britain provided the main active microwave instrument for ERS-1, along with a precision instrument, the Along-Track Scanning Radiometer (ATSR), to measure thermal emissions from the sea surface. In 1992 the ATSR produced highly accurate measurements of sea surface temperatures; the results are being fed into large computer models to gain further understanding of the Earth's climate and its changes.

Predicting Crop Yield from Space

A British Earth Observation demonstration space project launched in July 1993 could result in multi-million pound savings for the European sugar beet industry. The project will develop a sugar beet yield prediction system, using a range of satellite data, including ERS-1 data. It aims to demonstrate the viability of the technique and then to exploit the technology by selling a yield prediction service to sugar beet companies in Europe and the United States.

The three-year demonstration project, which involves the BNSC, will be carried out by a consortium which includes the Logica space software company, British Sugar, Broom's Barn Experimental Station and Nottingham University.

British Sugar annually produces 1.3 million tonnes of sugar from 9 million tonnes of sugar beet. The project could lead to combined savings of up to £1.8 million a year.

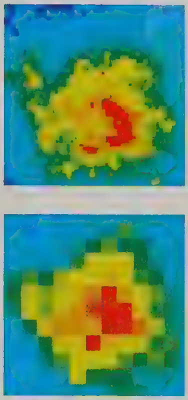
MERLIN

Large steerable telescopes like the Lovell telescope are very efficient at collecting the weak cosmic radio waves but less good at discerning fine detail in radio sources. For projects which need high resolving power (the ability to see fine detail), Jodrell Bank scientists have adopted a method – invented by Martin Ryle and colleagues at Cambridge University in the 1950s – of making small radio telescopes imitate much larger telescopes by linking them electronically.

MERLIN (Multi Element Radio Linked Interferometer Network) is an array of seven observing stations that together form a powerful telescope with an effective aperture of over 230 kilometres. MERLIN can see detail as fine as that of a human hair from a distance of several kilometres and has made Jodrell Bank pioneers in high resolution radio astronomy.

The MERLIN project was formally completed in late 1990 and has quickly produced outstanding results. In late 1991, for example, MERLIN observed patterns in the sky which point to the existence of dense clumps of matter at a very early stage in the evolution of the universe. This has spectacularly advanced the study of gravitational lenses, predicted by Einstein's General Theory of Relativity.

The 32-metre, 100-tonne radio telescope at Cambridge, which is linked to six others to form part of the MERLIN network.



An example of the improved resolution possible with the Hubble Space Telescope. The lower panel shows a typical ground-based view, while the upper panel shows a Hubble Space Telescope image of a spiral galaxy in the cluster AC114 seen face on.

The Earth Observation Data Centre at Farnborough (Hampshire), operated by the National Remote Sensing Centre Ltd, processes the data from ERS-1 and successor missions. This data is distributed to scientists and commercial users and makes vital contributions to many global environment programmes.

Britain will continue to have an important role in future remote sensing programmes. Matra Marconi Space (UK) provided the platform and instrumentation for ERS-2, launched in early 1995, for which Britain supplied a more advanced version of the ATSR flown on ERS-1. British Aerospace is prime contractor for the design and manufacture of the ESA Polar Platform. This polar-orbiting Earth observation satellite is to be used in the ENVISAT-1 programme – the first of a new generation of ESA environmental satellite missions to utilise the Polar Platform. British industry will have significant roles both in the ENVISAT payload and the ground-based data handling and exploitation system.

The *Cassini/Huygens* mission of the ESA and NASA, due for launch in 1997, will study Saturn and its moon Titan (a body thought to have a hydrocarbon sea). Britain is leading two of the multi-national mission's seven experiments and will participate in a further seven. Four complete instruments for both craft are being provided by groups from Kent, Oxford and other universities.

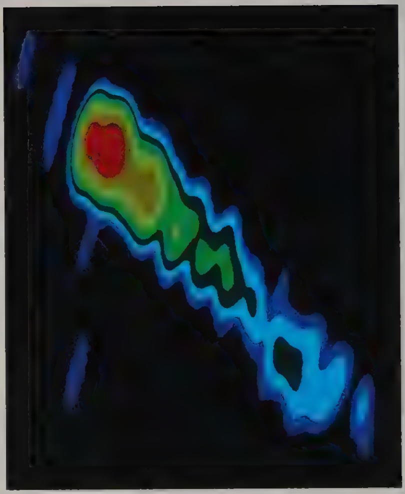
Astronomy and Planetary Missions

Britain has to date taken part in all of the ESA's missions to explore the Earth's nearest neighbours in space and observe and investigate distant stars and galaxies. These range from the investigation of Halley's Comet and the comet Grigg-Skjellerup by the British-built Giotto spacecraft to participation in the NASA (National Aeronautics and Space Administration) Hubble Space Telescope which, following the successful servicing mission at the end of 1993, is producing clear images at the limits of the observable universe (see p. 21).

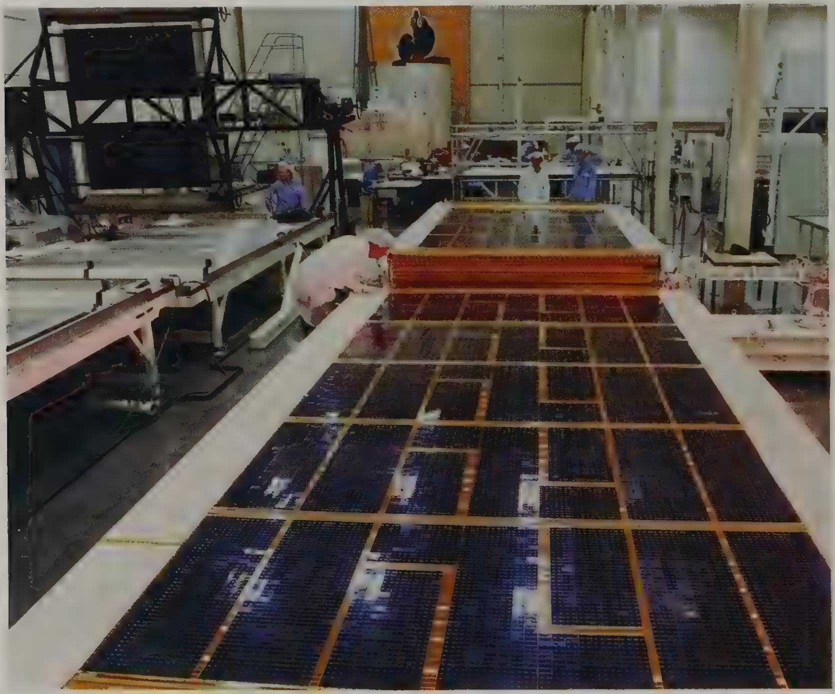
Britain is contributing substantially to the joint ESA-NASA Cluster and Solar Heliospheric Observatory (SOHO) missions to be launched in 1995 to study the sun, the Earth's magnetosphere and the solar wind.

SOHO is part of an international effort to understand the sun and its influence on the Earth. Cluster will observe the interaction of the solar wind with the magnetosphere, and its observations will be complemented by the ground-based radars of EISCAT in northern Scandinavia.

There are bilateral arrangements for space research between Britain and other countries, notably the United States through NASA, the Commonwealth of Independent States and Japan. In a major programme of X-ray astronomy, British scientists constructed the wide field camera for ROSAT, the German/UK/US satellite, and are constructing instruments for the Russian Spectrum X and ESA XMM Missions. British groups have taken part in the Japanese X-ray solar mission YOHKOH and the X-ray astronomy mission GINGA.



False-colour radio image of quasar 3C 273, at a wavelength of 18cm, showing the innermost portion of the quasar's enormous jet. The quasar itself (red, upper left) is thought by many astronomers to be a black hole lying at the centre of a faint, distant galaxy. The jet is a beam of fast-moving charged particles ejected from the nucleus and extends an estimated 1.2 million light years. Quasar 3C 273 is the nearest known quasar, lying some 2,100 million light years away from Earth. The colours represent intensity of radio emission, ranging from red (highest intensity) through to blue (lowest intensity).



Final inspection of one of the huge double-roll-out arrays for the Hubble Space Telescope built by British Aerospace under contract to the European Space Agency. The arrays, positioned either side of the telescope, contain over 48,000 solar cells in a total area of 34 sq m. The power output – converted from sunlight – is 4,600 watts; the weight is under 59 kg.

Britain's Instrumentation for Recent Space Missions

- *Launched in 1985, ESA's* Giotto *spacecraft passed within 600 km of the nucleus of Halley's Comet in 1986. Despite damage to its on-board TV camera from the high speed impact with the comet's dust particles, the spacecraft remained operational and was able to be retargeted to pass close to a second comet, Grigg-Skjellerup, in 1992. The craft's Dust Impact Detection System, developed jointly by the Rutherford Appleton Laboratory and the University of Kent, successfully registered the impact of dust particles – confirming the prediction that the comet was old compared to Halley. The craft remains operational and may be used in a cometary approach.*
- *The Hubble Telescope, launched in 1990, carries British built solar arrays and the British designed Faint Object Camera, both provided by ESA. Despite the well-publicised 'spherical aberration' in its optics, early observations were improved by British software which reconstructed the image by reversing the optical distortion. Following the servicing mission of December 1993, the Telescope is now producing images of great clarity, and British astronomers are active in its use. The ability to resolve very faint objects at great distances is contributing significantly to understanding the nature and origins of the universe.*

Big Science

Research in particle physics and nuclear structure physics (the study of the elementary constituents of matter and their constituents) is supported by both the EPSRC and the PPARC and co-ordinated by the Rutherford Appleton Laboratory. The Laboratory's physicists and support staff take part in experiments in collaboration with university groups as well as contributing to theoretical physics studies.

Nuclear Physics

During recent years British physicists have made impressive advances in nuclear structure research, including the original discovery of superdeformed, rapidly spinning nuclei; the discovery of new examples of proton radioactivity; and important studies of the clustering of nuclei – the so-called nuclear module. Recent achievements include theoretical progress to show how defects such as cosmic strings may leave distinctive signals in the cosmological microwave background, and the discovery that aluminium uptake in the body may be 100 times greater than previously thought.

Experimental observation of spinning nuclei requires highly sophisticated equipment, consisting of detectors which measure the amount of gamma-ray energy emitted. British and French scientists have constructed EUROGAM, the world's most advanced gamma-ray spectrometer.

The scientists will initially use EUROGAM's detector array to study nuclear matter under the most extreme conditions, such as nuclei rotating at extreme velocities. EUROGAM will operate in conjunction with the Daresbury Recoil Mass Separator, a highly sensitive device for identifying species of nuclei which emit gamma rays. Together they will provide an unparalleled facility for studying the nucleus.

The late John Bell on site at CERN. By means of a simple thought experiment, he showed that certain statistical predictions derived from quantum theory conflicted with those expressed in the theorem which bears his name – which is derived from our normal self-evident ideas of reality and causation. These predictions have been tested experimentally and quantum theory confirmed, thus bringing its disturbing consequences firmly into the realm of established fact.

ISIS

The Rutherford Appleton Laboratory's ISIS machine, the world's most intense source of pulsed neutrons and muons, is used by scientific teams from over 20 countries to probe a range of materials, such as high-temperature superconductors. In 1992 ISIS was used to perform around 600 experiments.

The low-energy neutrons produced by ISIS are able to reveal geometrical details of atoms and molecules in widely used materials such as industrial polymers, liquid crystals, hydrogen storage alloys and anaesthetics.

The EPSRC is to fund the construction of a test-bed for radioactive nuclear beams on the ISIS machine. This area of research is a priority topic in nuclear structure physics and it is hoped that the successful development and use of the test-bed facility might influence potential international partners in their final choice of site for a substantive research facility.

Synchrotron Radiation

The United Kingdom Synchrotron Radiation Source at the Daresbury Laboratory provides very high-energy radiation, from X-rays to the infra-red part of the electromagnetic spectrum. It is used by some 2,000 British and overseas scientists to investigate, among other things, the expression and suppression of genes and what happens when chemical 'messengers', large protein molecules, arrive at receptor sites in living cells; and what happens at the boundaries between two different materials in semiconductors.

The world's first continuously variable wavelength, ultraviolet microscope has been installed at Daresbury. Funded by the EU, it will be used to provide 'optical slice' images through biological and other materials.

The underground circular path of the Large Electron-Positron Collider (LEP) at CERN, the European centre for particle physics near Geneva, is marked by the dotted line. It follows the border between France (top) and Switzerland. Geneva airport is in the foreground.

Inside the Large Electron-Positron Collider (LEP) at CERN. LEP accelerates electrons and positrons to an energy of 50 GeV. It is housed in a circular tunnel 100 m underground and 27 km in circumference. The particles travel in opposite directions inside a narrow aluminium pipe which passes through large electromagnets. The long magnets bend the particles around the ring; the square blue ones focus them in tight bunches. The particles collide at four points around the ring.

Particle Physics

Particle physics experiments require the use of large colliders and accelerators, which form the basis of a number of international collaborations performed at overseas laboratories, particularly CERN, the European Laboratory for Particle Physics in Geneva.

The current CERN programme is focused on the Large Electron-Positron Collider (LEP), the world's largest operating particle collider, with British physicists and engineers collaborating in the design and construction of three out of four highly sophisticated experiments currently in progress. British physicists are playing an important role in designing experiments for the planned new Large Hadron Collider (LHC) at CERN, which has been accepted as the next step for research in this field. They are also collaborating in the two major experiments at HERA, the electron-proton collider at the Deutsches Electronen Synchrotron (DESY) Laboratory in Germany; both are designed to explore the internal structure of the proton and its constituents.

Scientists at St Andrews University in Scotland are to build a radical new type of spectrometer, able to observe chemical, biological and physical reactions that are too swift and faint to be seen with existing instruments. With backing from the EPSRC, they will develop a 'quasi-optical' electron spin resonance (ESR) spectrometer. ESR is a technique with important applications in medical research and the development of new drugs. It is also useful in fields ranging from forensic science to studies of new materials such as high temperature superconductors.

In late 1991 the Joint European Torus (JET) research team at Culham, Oxfordshire, successfully carried out an experiment which it claimed demonstrates the scientific feasibility of thermonuclear fusion. Instead of splitting heavy atoms of uranium, as is done in nuclear power stations, fusion combines light atoms (of hydrogen), releasing energy. The JET device, called a tokamak, is reported to have produced an energy release equivalent to 1 megawatt for two seconds. This is regarded as potentially a big step towards the production of virtually unlimited, safe and clean energy.

Applied Science

Electronics and Communications

British scientists, research organisations and firms have been responsible for some of the most important inventions in radio, television and radar, which formed the basis for the growth of the modern electronics industry. Products pioneered in British companies and elsewhere are often licensed to overseas manufacturers.

Current research areas include opto-electronics, molecular electronics, advanced control technology, advanced silicon technology and design automation. Priority areas include software and supercomputing in engineering.

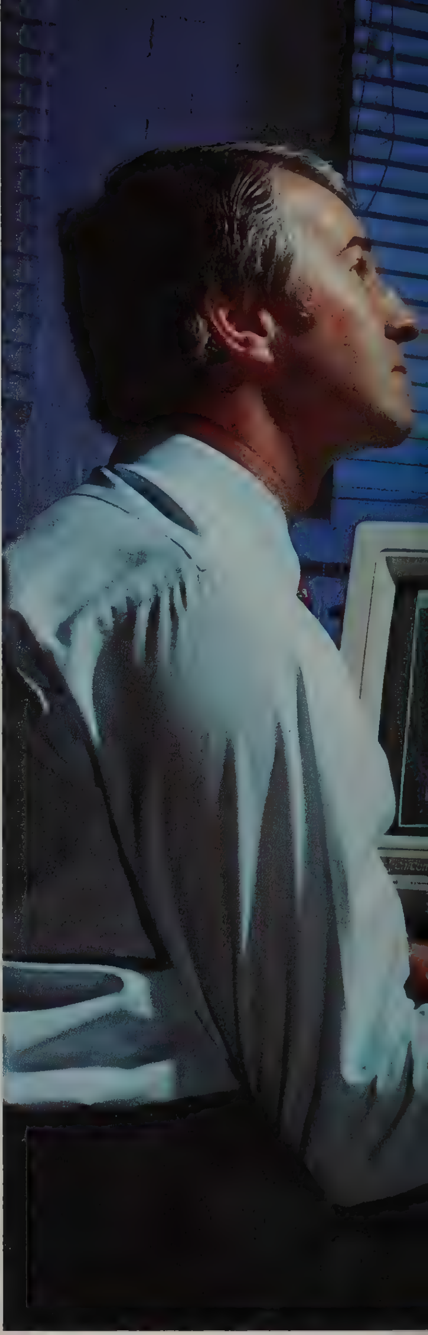
Electronic systems in computer-aided design, process control instrumentation and robotics are commonplace in manufacturing industry. Robotics are used extensively on production lines in the motor industry, and advanced electronics is incorporated into the vehicles that are manufactured. Companies such as GEC and Oxford Instruments develop and produce analytical instruments for industrial research and advanced electronic medical equipment, including ultrasound scanners, patient monitoring systems and magnetic resonance imaging (see p. 55).

Technology for the Textile Industry

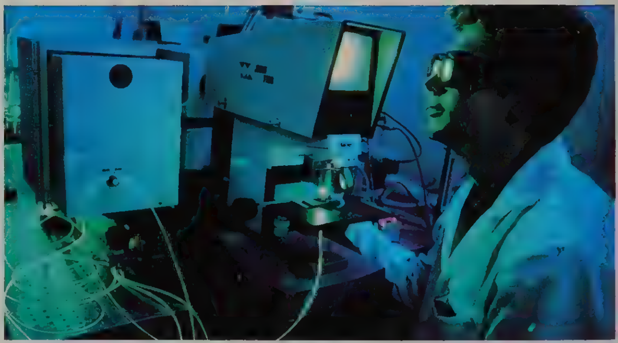
A three-year collaborative research project is under way at the CIMTEX (computer integrated manufacture of textiles) Centre at de Montfort University, Leicester. Using machinery donated by manufacturers and funding from the DTI, CIMTEX researchers, with industrialists and four other British universities, are investigating new ways of working in the manufacture of knitted garments.

The research aims to have small groups of workers involved in the total production of the garment, with each worker undertaking more than one operation in the manufacturing process. Two prototype production lines are being built: a semi-automated line centred on the operator, and a completely automated one requiring minimum supervision.

Other new working methods are being developed, including automated inspection of knitted fabric; new approaches to computer-aided design; robot stripping of the cutting table, which involves taking the pattern pieces of the garment off the cutting table and sending them down to the sewing cell; and automated pressing after garments have been transported by conveyor to a finishing station.



Computer-assisted Design and Manufacturing (CAD-CAM) techniques are used to produce individualised hip joints at the Royal National Orthopaedic Hospital, London. The overall outlines and key dimensions of the femur can be determined through the analysis of special radiographic views and computed tomography scans. The data is input to the computer by digitising and from this a specially written software package designs an optimally fitting artificial hip.



A technician monitoring the quality of optical fibres during manufacture.

Radar was invented in Britain and British firms are still in the forefront of technical advances. Racal Avionics' X-band radar for aircraft ground movement control is in use at airports in several countries. Solid-state secondary surveillance radar, manufactured by Cossor Electronics, is being supplied to 50 overseas civil aviation operators.

A printed liquidic circuit system for performing instant chemical analysis in the doctor's surgery has been developed by scientists at Birmingham University. The device can test for a range of conditions, including pregnancy, cholesterol levels, and HIV antibodies.

The world's first portable radar display unit, developed in Britain, will enable coastal policing and marine pilot navigation to be made more effective.

The Pilotwatch system, developed by the firm dB Electronics, can be carried around by marine pilots and when they are on board ship it can be linked to a shore-based Pilotwatch fixed radar so that the relative position of the ship can be seen in the context of land and other shipping rather than having to rely on radar pictures being produced by the ship's own radar. The Pilotwatch system can broadcast radar pictures from any number of radar stations to any number of portable receivers.

Physical Sciences

Applied Science

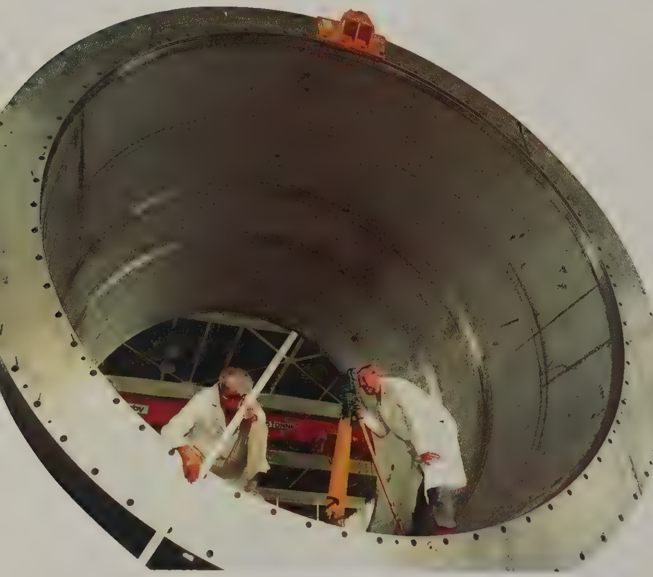
Superconductors

New ceramic materials developed by GEC Marconi are showing promise of being superior to all known high-temperature superconductors (materials with low electrical resistance). Patent applications have been filed on three materials based on cadmium, lead and copper oxides, which have been found to be both stable and reproducible. The research was part of a multinational EU project dedicated to developing superconducting cables and conductors operating at liquid nitrogen temperatures and above.

By the end of the decade the ability of superconducting materials to lose all resistance to electrical current at high temperature is expected to lead to applications in power generation and transmission, electromagnetic stores for off-peak electricity and transport systems using magnetic levitation.

The world's highest-temperature superconductor is currently being produced by a research unit at Cambridge University.

Six metres high and weighing 75 tonnes, this giant magnet is a superconducting solenoid built at the Rutherford Appleton Laboratory, Oxford, for the international HERA project in Germany. The solenoid is used to bend the particles produced by collisions between electrons and protons in order to determine their momentum and electrical charge.



Loughborough University researchers are working on a system that translates the eye movements of a person with disabilities into computer commands. They have produced a binocular eye-tracking system which monitors eye positions and sends the computer screen cursor to wherever the person is looking.

Iann Barron with a transputer chip and silicon wafer inside the INMOS factory at Newport, South Wales. The transputer is a single silicon chip which, when connected together with others, can produce unlimited processing capacity. In a short time it has become a world-wide success, providing the basis for new parallel processing systems.

Computing Services

Britain has made important contributions in opto-electronics (the combination of optics and electronics) and parallel computing, which is based on transputers working in parallel to give the same capacity as a supercomputer.

In 1983 Inmos, then a subsidiary of THORN EMI, produced the transputer, which combines all the main functions of a simple computer on a single chip.

British companies, such as Kerridge Network Systems, which develops programs for portable computers, are in the forefront of software development. British firms and research organisations, with government support, have been involved in the development and application of the new family of 'three-five' semiconductor materials (such as gallium arsenide). In 1984 GEC released the first commercially available gallium arsenide microprocessor, which can operate at much higher frequencies than the common silicon type. The Trax, a novel design of supercomputer processor with a wide range of applications, including high-definition television and defence systems, was originally developed at Brunel University, near London.

An engineer at Britain's Advanced Robotics Research Centre using the Advanced Tele-operation Controller, a British invention which can guide a robot arm remotely. The operator uses a hand control device while looking at a TV screen and the robot arm faithfully simulates what is on the screen. Robot performance, particularly at high speed or with large payloads, is usually severely limited by the design of the controllers which guide the movement of the robot's joints and limbs.

The Advanced Robotics Research Centre in Salford is conducting research into 'virtual reality' (VR) technology – the three-dimensional computer simulation of the outside world triggered by electronically detected body movements. It is developing a pneumatic glove designed to generate force and tactile feedback for the VR user. VR is being used to design buildings and a range of products, including cars, pharmaceuticals and machine tools.

Applied Science

Networking

The Rutherford Appleton Laboratory provides some computer services on behalf of all the research councils. In 1992 a new Cray supercomputer was installed at the Rutherford Appleton Atlas Centre and connected to the Joint Academic Network (JANET – see below).

With three times the power of its predecessor, it will facilitate major research work in oceanographic and atmospheric science, studies of new materials and processes, design of drugs, and realistic simulation of complex structural and fluid flow problems in engineering applications.

The ESRC's new Centre for Research in Development, Instruction and Training has successfully tested a new electronic teacher on children as young as three years old. The EXPLAIN computerised teaching system mimics up to five different ways in which parents support children's learning. By means of interactive videos it can provide support contingent to each child's ability, providing more or less help as needed. Tests on children aged three to eight showed that those taught in this way greatly outperformed those taught by non-interactive video or photographs. The researchers believe that the system can help teach children with learning disabilities, improve teacher training, and also dramatically cut the time companies spend on training workers.

BT and the academic community are collaborating on the development of SuperJANET (the Super Joint Academic Network – see box), a new high-speed fibre optic network which will link computer systems in higher education and research institutions in Britain. SuperJANET will complement JANET, which currently links 200 sites and has served universities and

SuperJANET: High-speed Computer Network

Funded by the Higher Education Funding Councils, SuperJANET can transmit information a thousand times faster than any other system currently available. SuperJANET can, for example, transmit the equivalent of a 5,500 page report in less than one second.

The increased power of SuperJANET comes from the use of fibre-optic links between computers and users, allowing massive amounts of data, graphics and visual images to be flashed across the network. The new network will open up entirely new ways of storing, processing and distributing information.

- *SuperJANET is expected to support a wide range of teaching and learning activities. The teaching may be live and interactive – for example, by allowing medical students in a number of locations to watch and talk to a surgeon performing an operation.*
- *SuperJANET will enable people at different locations to exchange and manipulate intricate 3D images while at the same time seeing and talking to each other as if they were in the same room. For example, a pathologist examining a microscope slide while at one location can transfer the image via SuperJANET to a colleague at another location on the network. Both consultants would be in visual and voice contact so they could discuss the image, magnifying certain parts of it, move the slide around under the lens, and draw common conclusions.*
- *SuperJANET will allow the use of two supercomputers in different locations to work on the same problem simultaneously and also provide access for a user at a third site.*

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The BT Worldwide Management Network Centre, in Oswestry, can locate trouble spots in the company's inland and international networks. The video wall in front of the control consoles – at 25 metres the longest in Europe – gives rapidly updated information on the state of the networks, allowing the network managers to take immediate action to prevent congestion.

Applied Science

Aerospace

The Anglo-French Concorde – powered by four Rolls-Royce/SNECMA Olympus engines – is the world's first supersonic passenger aircraft. The aircraft carries 100 passengers at speeds around Mach 2 (2,170 km/h) over journeys of 5,630 km, cutting journey times by about one-half.

Britain has led the world in many aspects of aerospace R & D over the last 80 years. Pioneering achievements involving British technologists and aviation specialists include radar, jet engines, Concorde, automatic landing, vertical take-off and landing, flight simulators, swing-wing military aircraft and ejector seats. About 13 per cent of Britain's investment in industrial R & D goes to the aerospace industries.

Most developmental work is carried out by industry, with some assistance from government research establishments. A substantial amount of long-term aerospace research and formal trials work is conducted in partnership with universities and industrial research centres. Most of the Government's spending on aerospace R & D is concerned with military programmes.

Among important technological advances in aviation equipment, British Aerospace, with Marconi and Dowty Boulton Paul, developed a system known as 'fly-by-wire', in which flying control surfaces are moved by electronic rather than mechanical means. In 1988 GEC Avionics also developed the world's first fibre-optically signalled ('fly-by-light') aircraft control system.

The concept of head-up display (HUD) was pioneered and developed in Britain. This system electronically projects symbols into the pilot's view, avoiding the need to look down at instruments. GEC Avionics developed a holographic HUD, which enables pilots to fly at high speeds at very low altitude in darkness. Aerospace companies such as British Aerospace, Smiths Industries and GEC-Marconi carry out R & D in a vast range of equipment for civil and military aircraft, such as navigational equipment, sophisticated radar and air traffic control systems and flight control and landing systems. British Aerospace has developed a Terrain Profiler Matching System, which compares aircraft height with a digital map store in its memory. GEC-Marconi's airborne computer can produce colour maps on cockpit electronic displays.

British companies like Cossor, GEC, Plessey, Racal and THORN EMI Electronics are world leaders in radar technology. Siemens Plessey and Racal are developing Microwave Landing Systems, set to replace the Instrument Landing Systems in current use.

The Trent aerospace engine, the latest and most powerful of the Rolls-Royce RB211 family.

Martin Baker has produced 67,000 ejector seats for a total of 87 Air Forces and is the leading manufacturer of aircraft escape systems. The company design, tests, manufactures and supports some 75% of the western world market for these technically advanced systems that have saved over 6,400 aircrew lives.

Aerospace Engines

Rolls-Royce is one of the Western world's three leading manufacturers of aerospace engines. Its most important civil engine is the RB211 turbofan, several versions of which have been developed. The RB211-524G and 544H are the latest to enter service. They feature Rolls-Royce's unique wide-chord fan blades, together with an electronic fuel control system, giving improved thrust and fuel efficiency. The RB211-544H's modular design allows it to be upgraded to incorporate new technological advances.

The development of larger-capacity aircraft means there is a need for engines of 50,000 lb or more thrust. Already leading the market is the latest Rolls-Royce development – the Trent, the world's most powerful turbofan, rated at 65,000 – 85,000 lb and due to come into service during 1995.

In September 1993 Rolls-Royce announced two new research programmes for military aircraft. Funded jointly by the MoD and Rolls-Royce, the first project will investigate and demonstrate ways of applying advanced technologies to combustors and high-pressure turbines for use in combat engines. The second will demonstrate advanced compression systems, low-pressure turbines, reheat systems and nozzles. Both programmes, aimed at boosting the performance of combat planes in the future, also have 'spin off' into civil engine developments.

A £2.7 million grant from the DTI helped a group of four companies and a university to develop 'Fire Spear' – a firefighting device which can drill through an aircraft side in seven seconds, and then switch to a high-pressure fogging water spray. The device is based on innovative water motors, which use water both as a power source and a lubricant. It creates a water curtain, enveloping toxic gases and preventing the sudden spread of fire. The Fire Spear is now being evaluated and has attracted international interest.

Eurofighter 2000, one of the world's most advanced aircraft, is a co-operative venture between Britain, Germany, Italy and Spain.

Life and Medical Sciences

Medicine and Genetics

MANY far-reaching scientific advances are being made in Britain in medicine, genetics, biotechnology, and pharmaceuticals.

For example, Britain continues to make outstanding contributions to organ transplant surgery and medical diagnostic techniques. Exciting recent discoveries include: the identification of genes linked to certain diseases such as cystic fibrosis, and the subsequent development of gene therapies; the development of artificial blood; and the development of a treatment for rheumatoid arthritis using humanised antibodies.

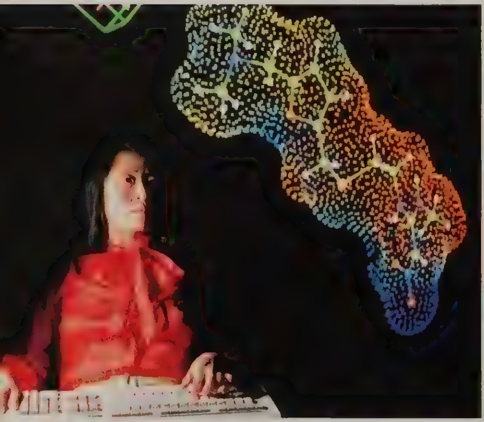
Britain has a particularly strong reputation in protein engineering and antibody research, and many of the British research teams working in the life sciences have established international reputations.

As in other leading medical research centres worldwide, the effort devoted to molecular genetics funded by the Medical Research Council (MRC) has increased substantially in recent years, reflecting the growing importance of this area in the development of drugs, vaccines and diagnostic techniques. A prominent interest at the MRC's National Institute for Medical Research is embryonic development. Using mouse embryos, this research focuses on the part played by so-called 'homeobox' genes in the control of embryonic development in many species, including humans.

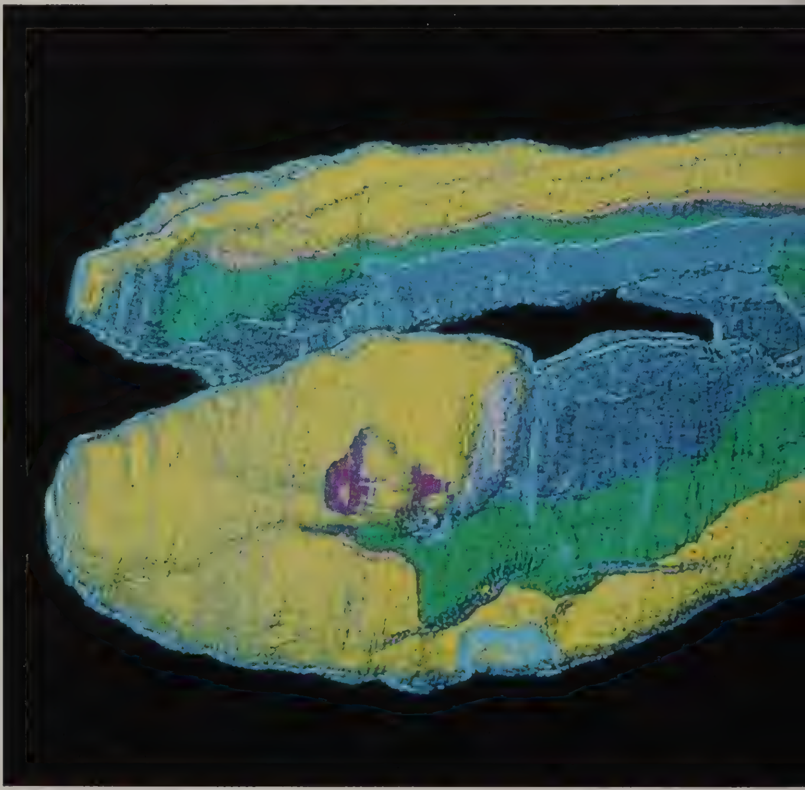
Some of the more recent important medical developments funded by the MRC and examples of the work of cancer research charities are outlined below.

Gene Therapy for Cystic Fibrosis

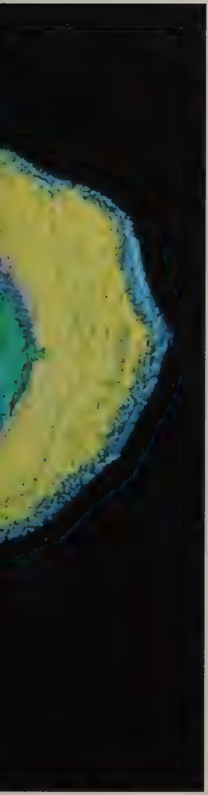
In August 1993 the Royal Brompton National Heart and Lung Hospital in London began its first trials for treating sufferers of the inherited disease cystic fibrosis by gene therapy. The therapy, administered by spray into the nose and lungs, contains a normal functional copy of the defective gene, packaged in minute fat globules (liposomes) which fuse with the recipient's cell membrane. The gene then works inside the



A scientist uses a computer to manipulate a graphic model of a molecule. A knowledge of the distribution of electrostatic charge across the molecule allows the scientist to predict and design reactions with various functional groups of atoms to produce new molecules. This is an increasingly important part of drug design and the study of protein.



A 3-D computer reconstruction of a 9-day mouse embryo showing the developing neural tube (yellow), gut (green), notochord (pink), ear rudiment (grey) and some other tissues. This BBSRC-supported project is part of a large programme shared between the MRC, Jackson Laboratory (USA) and Edinburgh University to develop a publicly accessible computer database that will contain text and graphical information about when and where each gene is expressed in the developing mouse (the model for most mammalian work).



Britain is in the forefront of genetics research, and is one of the main countries involved in the process of isolating and mapping the complete sequence of genes – the genome – in the cells of humans. This research, and the study of gene products, has vast potential for the understanding of human biology and many diseases.

Once the human genome is fully decoded, it will be possible to identify the risks of hereditary diseases faced by any individual by examining a single cell or blood sample. It will also be possible to predict their predisposition to multi-factorial diseases not due primarily to genetic disorders, such as heart disease or lung cancer.

The project requires a high level of international collaboration and several countries have begun their own national projects to map the human genome. Building on Britain's strong tradition of research in human genetics, the MRC set up the UK Human Genome Mapping Project in 1989, with a budget of £11 million over three years. Genome research in Britain is conducted in higher education institutes, MRC establishments and centres supported by other agencies such as the Imperial Cancer Research Fund and the Wellcome Trust. The MRC has also established a Human Genome Mapping Project Resource Centre, which provides services and reagents to British and European research communities, including to industry. The Resource Centre is located on a new 'genome campus' in Cambridge, which also houses the Sanger Centre, a large-scale sequencing factory, jointly funded by the Wellcome Trust and the MRC, and the European Bioinformatics Institute, an outstation of the European Molecular Biology Laboratory.

cell to produce the protein whose absence allows the lungs to fill with mucus and make the patient prone to infection.

The cystic fibrosis gene was identified and isolated as recently as 1989. Scientists at Oxford and Cambridge Universities used genetic engineering techniques to produce a mouse with many of the characteristics of cystic fibrosis in humans. Using these mice as models, they injected a normal copy of the defective gene into their airways and restored them to normality. Scientists at the MRC Human Genetics Unit at Edinburgh developed another mouse model which mimicked more closely the disease characteristics. They then refined the gene complex into a spray that could be inhaled by sufferers of the disease. Patient trials are in progress.

Performing a brain operation at the Royal Victoria Hospital, Belfast. The Royal, which enjoys an international reputation for its pioneering work in areas of specialist surgery, developed the technique of replacing damaged portions of the skull with lightweight titanium plates.

Human Genome Mapping Project

A major national research project at the MRC is the Human Genome Mapping Project, involving mapping of the complete sequence of 100,000 genes in a human cell.

In 1992 the MRC received substantial additional funding for an initiative in the Genetic Approach to Human Health. This builds on the Human Genome Mapping Project, encompassing all aspects of genetic diseases and their future treatment. Three centres of expertise in gene therapy have been established in Birmingham, Edinburgh and London. The centres aim to treat patients with inherited disease by inserting a healthy copy of a faulty or missing gene into cells in the patient's body.

Cancer

The prospect of injecting 'killer' genes into cancer cells is one of the most promising areas of medical research. Imperial Cancer Research Fund scientists have developed a gene therapy for malignant melanoma, a fast-increasing form of skin cancer. Human trials began at the Fund's Oxford Clinical Oncology Unit in late 1993. The first vaccine to protect specifically against cancer has been developed by British scientists funded by the charity Cancer Research Campaign (CRC). The result of more than 25 years' research, and a total investment by CRC of £5 million, the vaccine will be used to protect against the Epstein Barr virus (EPV), which is associated with a number of different cancers. The MRC is supporting gene therapy for cancer at two of the three gene therapy centres it has recently established.

Other Recent Genetics Discoveries

- *British scientists, collaborating with researchers in the United States and other countries, have confirmed the discovery of a gene which is responsible for both breast and ovarian cancer in some families.*
- *The MRC's animal-to-man transplant programme in collaboration with the BBSRC has produced the world's first transgenic pigs – pigs into which human genes have been inserted. These are bred to supply tissue and organs the human immune system will accept.*

Photodynamic therapy is a new treatment for cancer which depends on killing cancer cells by first making them highly sensitive to light. The idea, developed at University College Hospital, London, has been used to deal with cancers of the mouth that, until now, have been unresponsive to existing treatments. Stephen Bown, Imperial Cancer Research Fund professor of laser medicine and surgery at the hospital, believes the treatment should be applicable for killing many other tumours and for destroying residual cancer cells that so often cause problems after surgical operations. The patient is given a drink made with a powder that supplements the normal levels in the body of ALA (aminolævulinic acid), a substance that regulates the normal sensitivity of tissues to light. The increased receptiveness to light from the extra ALA is not restricted to tumour cells, but the effect wears off in 24 hours. In the period of raised sensitivity, the doctors shine a beam from a low power laser, by means of a glass fibre, directly on to the cancer cells while they are vulnerable to light.

The MRC supports basic molecular and cellular studies on cancer, its genetic predisposition, detection and diagnosis, and measures to improve treatments, including clinical trials.

To complement the work of the medical charities and the Department of Health, the MRC's strategies in cancer research are focusing on the understanding of tumour biology.

Using nuclear medicine to fight cancer. A researcher at the University of Kent, in Canterbury, using British-built equipment, called a cryotome, to cut thin sections of frozen tissue which has been injected with radio-active drugs (radiopharmaceuticals). The university is developing a technique called frozen section microautoradiography which, used alongside computer image analysis, can measure the distribution of radiation at microscopic-cell-nucleus level. The technique can be used to measure the efficacy of radiopharmaceuticals in therapy and to estimate the risk associated with their diagnostic uses.

A technician at work in the government-financed Bio Products Laboratory (BPL) in Elstree, Hertfordshire. One of the world's most advanced plasma processing centres, BPL manufactures therapeutic blood products exclusively from unpaid voluntary donor blood plasma, an important factor in maintaining high standards of safety and quality.

Infections and Immunity

The field of immunity has undergone radical advances following the application of techniques used in molecular and cell biology and protein engineering. Recent MRC research on the role of peptides during the processing of antigens is contributing to vaccine development. Current work is aimed at understanding competing strategies in the immune system and the apparent effectiveness of infectious agents in exploiting these mechanisms. Other work is concerned with identifying the vulnerable stages of parasite life cycles in order to develop new drugs and vaccines to treat schistosomiasis and malaria.

The MRC plays a vital role in the international research effort to combat human immunodeficiency virus (HIV) and AIDS. Work is directed at developing antiviral drugs and vaccines, and assessing the extent of the epidemic and the behavioural factors of transmission.

A major long-term investigation into premature births started in Britain in November 1993. Funded by the MRC, its purpose is to test the idea that premature labour is frequently triggered by mild infections in the mother that could be cleared up by antibiotics. Over 10,000 women in 100 centres in Britain and abroad are expected to be involved over four years – the largest trial of its kind worldwide.

Scientists suspect the trigger for premature birth is the release of prostaglandins – hormones produced by the body's immune system when counteracting inflammatory disorders. The researchers believe that by treating the suspected infection they might be able to reduce the risk of early delivery.

The study, which is particularly concerned with mothers who go into premature labour between 24 and 34 weeks, is being co-ordinated by doctors at hospitals in Dundee and Leicester.

DNA fingerprinting: an X-ray (or autoradiograph) of bands of DNA produced by the technique of electrophoresis in an agarose gel. The pattern of the DNA bands is unique to each individual or other animal and forms a kind of genetic identity card. DNA can be used to prove whether people are related. The technique can also be used to identify and convict criminals from blood, hair, sperm or other tissue left at the scene of a crime.

Biotechnology

Biotechnology is the application of our advanced understanding of living organisms and their components to create industrial products and processes. BBSRC supports much of the research underpinning this 'biological revolution'. New experimental tools and methodologies are providing completely new insights into the behaviour of organisms at their most basic level. There are exciting opportunities in, for example, increased knowledge of genome organisation across species, understanding of the generic rules governing the folding of proteins, new molecular techniques for signalling, neuroscience, control of metabolic pathways and soil, microbe, plant interactions.

The techniques of molecular and cell biology derive from the discovery of the structure of DNA at Cambridge University in the 1950s (see p. 54). In particular those techniques used to identify and modify genes and to isolate genes and their products, are driving the development of new bioprocesses that underpin the biotechnology industry.

Biotechnology is expected to have a major impact in many industrial sectors by the next century. Its most advanced commercial applications are in pharmaceuticals and healthcare (see pp. 42 – 43), along with food, agriculture (see pp. 38 – 41) and the development of advanced materials, such as engineering plastics. Britain has made major advances in developing drugs such as human insulin and interferons, genetically-engineered vaccines and in producing antibiotics by fermentation; alternative bactericidal drugs based on Nisin, a food preservative made in Britain; medical diagnostic materials like biosensors; and agricultural products such as crop varieties that are resistant to infection or have improved qualities.

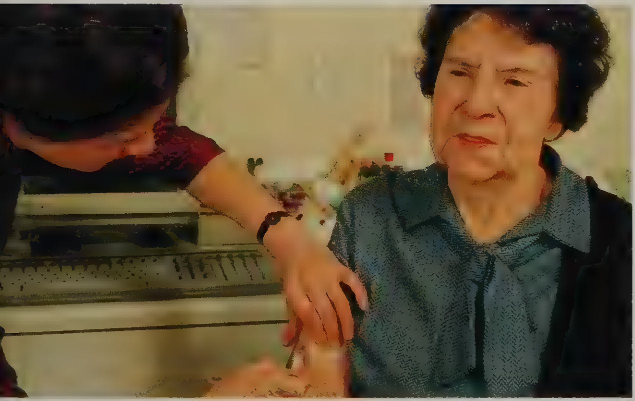
Major companies, such as ICI, Glaxo-Wellcome and SmithKline Beecham, undertake extensive research in biotechnology. ICI, for example, has developed Biopol, the world's first bio-degradable plastic. Britain's 50 small independent biotechnology firms tend to specialise in medical diagnostics, microbial pesticides, plant breeding, waste treatments and the production of specialised enzymes.

In 1985 the British company Celltech became the first company in the world to produce bioactive human calcitonin. This is the hormone used in the treatment of Paget's disease, a weakness in bone structure. The disease can now be treated using bioactive materials that interact with human tissue to form healthy bone.

In 1992 MRC scientists developed a treatment using humanised monoclonal antibodies which relieves rheumatoid arthritis symptoms for up to eight months. Using genetic engineering, they reshaped rat antibodies to appear like human antibodies, thus bypassing the body's rejection reaction. Further studies are in progress to lengthen the period of remission.

Scientists from Cambridge and Sheffield Universities and Cantab, a biotechnology company, have discovered a way of disabling a virus so that it can stimulate a full immune response without spreading within its host. They are using this technique to develop a vaccine against the genital herpes virus.

MRC scientists, together with a biotechnology company, Cambridge Antibody Technology, have used genetic engineering techniques to make human antibodies entirely outside the body without the need for immunisation. They will be attempting to make improved antibodies to treat diseases such as AIDS and cancer.



A Paget's disease patient receives a calcitonin injection. Paget's disease (osteitis deformans) is a common disorder of elderly people in which bone formation is disrupted, causing bone to weaken, thicken and become deformed. Usually the pelvis, collarbone, vertebrae and long bones of the leg are affected. Calcitonin is produced by the thyroid gland and controls levels of calcium in the blood. It slows the rate at which calcium is lost from the bones.

A research scientist at the Celltech laboratories using animal cell culture to produce monoclonal antibodies and genetically engineered proteins. One of the largest independent biotechnology companies in Europe, Celltech focuses its research on the study of proteins in the immune system, in order to develop new therapeutic drugs to combat immune disorders, inflammatory diseases and cancer.

Celltech has pioneered the mass production of monoclonal antibodies – artificially cloned proteins which can seek out a particular substance in the body. The antibodies are used to diagnose diseases, identify different blood types and can be used in the treatment of a range of conditions, including cancer.

A second generation of vaccines based on recombinant DNA technology includes SmithKline Beecham's Energix-B vaccine against hepatitis, which more than doubled its sales in 1992. Drugs are being developed that act on defective genes either in the human host or in the infecting organism.

Britain leads in the development of molecular graphics, which contribute to the rational design of new and improved medicines through a computer-aided technique for analysing the structures of complicated organic molecules on a visual display unit.

In 1991 Professor Alec Jeffreys of Leicester University – the inventor of DNA fingerprinting – announced his invention of a digitalised version of the DNA fingerprinting test.

The new genetic profiling technique will make DNA fingerprints more accurate and easier to distinguish. For the first time it provides a method where different forensic laboratories can exchange and compare information, enabling international DNA fingerprint databases to be set up.

The technique is up to 100 times as sensitive as the method commonly in use. Analysis of blood, semen, saliva or hair roots produces a digital code between 50 and 70 numbers long – an unambiguous signature. The test will also reduce the time it takes to produce the fingerprint from four weeks to two days. The new test is being marketed by the British company Cellmark Diagnostics.

Life and Medical Sciences

Agriculture and Food Research

Manor hybrids – genetically advanced pigs with a worldwide reputation for leanness – have been created by the National Pig Development Company, one of Britain's leading exporters of genetically-advanced pig breeding stock.

The government agriculture departments, the BBSRC and private industry share responsibility for research. This is carried out in a network of research institutes, specialist laboratories and experimental husbandry farms; and in higher education institutions.

Animal Science

BBSRC work on basic animal physiology and genetics at the molecular and cellular levels underpins more strategic research related to animal production, health and welfare.

The Council supports genome mapping, which will allow the genetic identification of a number of performance traits and heritable defects in farm animals. Council scientists are also responsible for co-ordinating an extensive European consortium which aims to produce a complete genetic map of the pig.

Recent developments have seen the transfer of transgenic technology to

A scientist at the University of Leicester at work on a research project that aims to provide pure water by treating it with seeds from the tree *Moringa oleifera*, which grows extensively in the tropical and sub-tropical regions of Asia, Africa and South America. The British researchers have discovered that the seeds, when mixed with river water, produce water-soluble proteins that are able to bind individual particles of material together to form a floc. Bacteria and viruses become enmeshed in the floc and after a period of slow mixing all the suspended materials settle out under gravity.

A postgraduate student from Indonesia studying techniques for the regeneration of plants from genetically transformed cells and tissues. The work, at the University of Bath, is part of an international programme aimed at improving the resistance of popular varieties of cassava to the African cassava mosaic virus. The programme uses genetic engineering techniques to transfer the coat-protein gene of the virus into African varieties of cassava.

industry; in 1992 a pharmaceuticals company, Pharmaceutical Proteins Ltd, further developed the production of the protein alpha-l antitrypsin in the milk of genetically altered sheep. This protein will be used in the treatment of emphysema.

Together with a British company, Animal Biotechnology Cambridge (Mastercalf), and the United States Department of Agriculture, BBSRC scientists have developed a technique for separating the X (female)- and Y (male)-carrying sperm of bulls. This has been used successfully to produce calves of predetermined sex.

Animal Disease Research

Using modern molecular biological techniques, Research Council and MAFF scientists have developed new vaccines against animal diseases of enormous international economic importance. These include:

- the Aro A live salmonella vaccine against salmonella in chickens;
- the capri-pox virus vaccine containing rinderpest viral genome, which protects against both lumpy skin disease and rinderpest in cattle; and
- a vaccine against mastitis in cattle.

A new diagnostic test for salmonella has also been developed by MAFF scientists and has received great interest worldwide, particularly by human diagnostic laboratories.

Food Science

Scientists at the BBSRC Institute of Food Research have solved the structure of the pectin-degrading enzyme, pectate lyase, which will open up ways of modifying the use of pectin as a gelling agent and improving the process of fruit juice clarification. The Council's scientists have also completed a comprehensive genealogical analysis of the genus *Bacillus.* The research has relevance to the agro-food and pharmaceutical industries as well as to health.

New Wheat Strains

Scientists working at the BBSRC Institute for Plant Science Research in Norwich have devised methods of genetically engineering new strains of wheat that will produce better bread and grow in hostile climates such as the deserts of the Middle East. The scientists have successfully hybridised wheat with a wild relative, a couch grass found in Crimean sand dunes. This hybrid is called tritipyrum and is able to grow in water half as saline as seawater.

In the Middle East and Pakistan, where the ground is already salty, intensive irrigation and evaporation tend to concentrate salt in the topsoil, making the land unsuitable for conventional crops. In the light of this, the researchers now plan to grow different versions of tritipyrum, using different couch grasses and varieties of wheat, in real farming conditions in the Middle East.

Plant Science

BBSRC research studies the genetic improvement of crops, the processes affecting crop yields and soil fertility, crop nutrition and protection, managed grassland ecosystems, lower input farming systems, possible alternative crops and novel, non-food uses for crops.

Significant advances have been made in the analysis of crop genomes, in the study of plant reproductive processes and plant/herbivore interactions, and in identifying and manipulating genes for plant products which can be used to alter pest behaviour. Hybrids with enhanced drought tolerance have been produced and new disease resistance introduced into white clover using wide crossing and embryo rescue techniques.

The order of genes within chromosome segments of wheat and rice has been shown to be the same. This discovery means that the whole plant and molecular genetics of rice will help future strategies in wheat breeding and the isolation of important genes.

The Council's scientists have successfully isolated a gene required for flower production. They found that when the gene was activated by a mutation, plants were unable to produce flowers but continually produced shoots instead. This discovery may eventually enable scientists to modify the pattern of flowering in a controlled way.

Controlling Slugs by Natural Means

*BBSRC-funded scientists have discovered that a minute worm (*Phasmarhabditis sp*) belonging to the roundworm family will attack and kill slugs, which cause millions of pounds worth of damage to crops such as winter wheat and lettuce each year.*

The worms' major use is likely to be in farming. They have considerable advantages over chemical pesticides since they attack only slugs, leaving other small creatures such as earthworms untouched. Fed on liquid food, the worms can be grown in vast quantities and then kept in a clay mixture under refrigeration until needed. The worms are now being produced commercially in a pilot plant by the Microbio division of Agricultural Genetics Company.

Engineering

Recent advances in BBSRC research include the development of mathematical models of spray dispersion, which can be used to estimate spray drift and deposition patterns for a range of crop, spray and environmental conditions. Collaborative research is showing which patterns are biologically the most effective. In 1992 the Council's scientists developed a computer-aided patch spraying system: instead of spraying the whole field, this system targets only those areas where weeds are growing.

Scientists at work in Zeneca's weed science glasshouse, at Jealott's Hill, Berkshire. Without agrochemicals, the world would lose up to 30 per cent more of its crops to pests, weeds and diseases.

Farm Projects in Thailand and the Philippines

- *In a project funded by the ODA, the Silsoe Research Institute, together with the International Rice Research Institute in the Philippines, has developed a promising small rice harvester. The pedestrian-controlled machine will enable small farmers to harvest rice with less labour, less grain loss, at less cost and in less time. The harvester can be easily manufactured and maintained locally.*
- *The tilapia fish is widely used in aquaculture as it is fast growing, tolerant of poor water quality and relatively disease resistant. Unfortunately it can reproduce whilst still very small and as a result fish ponds usually contain many small fish of very limited value. The ODA has funded a series of projects at Swansea, south Wales, and Central Luzon State University in the Philippines aimed at reliable production of all-male tilapia fish through genetic means.*

The so-called 'supermales' produced by this work have all-male progeny and hence can be distributed to farmers in the expectation that the fish harvested will be large and uniform in size. The latest project aims to extend the benefits of this research to farmers in Thailand and the Philippines.

Life and Medical Sciences

Chemicals

Britain's chemicals industry is at the forefront of modern technology, spending the equivalent of 6 per cent of total sales on R & D. Pharmaceuticals is the most research-intensive sector of the industry, while a large proportion of the world's R & D in agrochemicals is conducted in Britain. Its research expertise has led many overseas companies to establish research bases in Britain.

The chemicals companies increasingly devote their resources to developing specific products and processes, and as a result much of the basic research for Britain's chemicals industry is carried out in universities and other non-profit-making establishments.

The BBSRC supports research to help maintain the international competitiveness of Britain's chemicals and pharmaceuticals industries. Research themes include recombinant industrial products; synthesis of organic chemicals and natural products via bioprocesses; environmentally safe bioprocesses and bioremediation; and efficient manufacture of bioproducts.

Research performed by the chemicals industry over the last few years has led to significant technological and commercial breakthroughs. ICI is at the forefront of global efforts to develop substitutes for chlorofluorocarbons (CFCs); in 1991 it opened the world's first plant to manufacture ozone-friendly HFC 134a, a less damaging alternative to CFC, in Runcorn, Cheshire.

In agrochemicals, notable British discoveries include synthetic pyrethroid insecticides, ICI's diquat and paraquat herbicides, systemic fungicides and aphicides, and methods of encouraging natural parasites to attack common pests in horticulture.

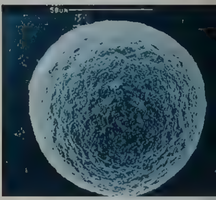
In the textile industry, Britain's second biggest chemicals company, Courtaulds, has developed a new solvent-spun, biodegradable fibre, Tencel, which is twice as strong as cotton but soft enough to be used by designers of luxury garments.

Pharmaceuticals

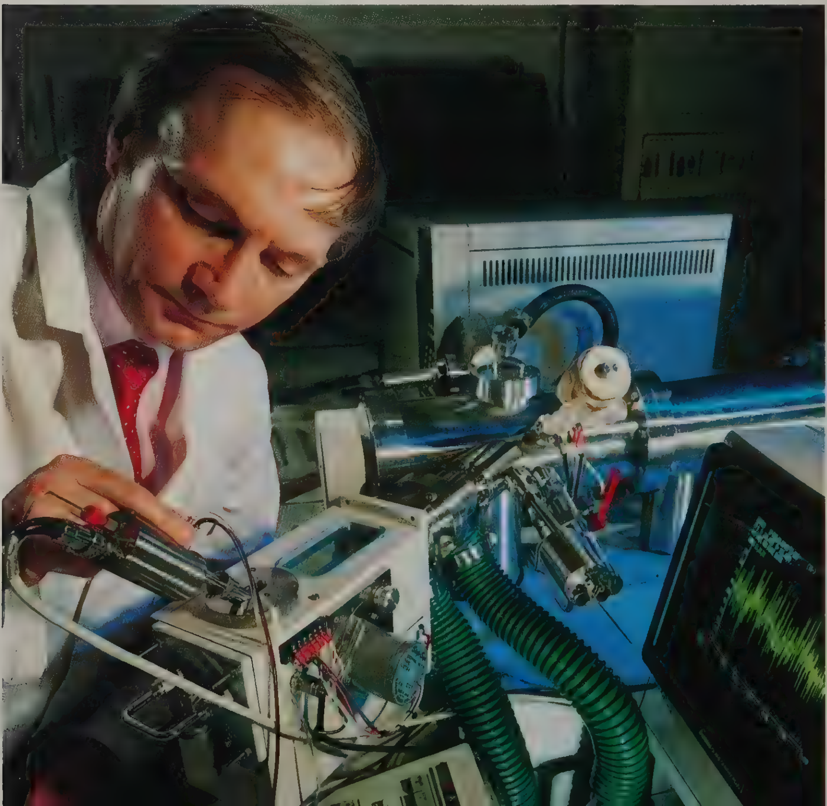
Britain is the world's fourth largest exporter of medicines. In 1992 the pharmaceuticals industry invested more than £1,450 million in R & D, representing about 8 per cent of total world spending on medicines research.

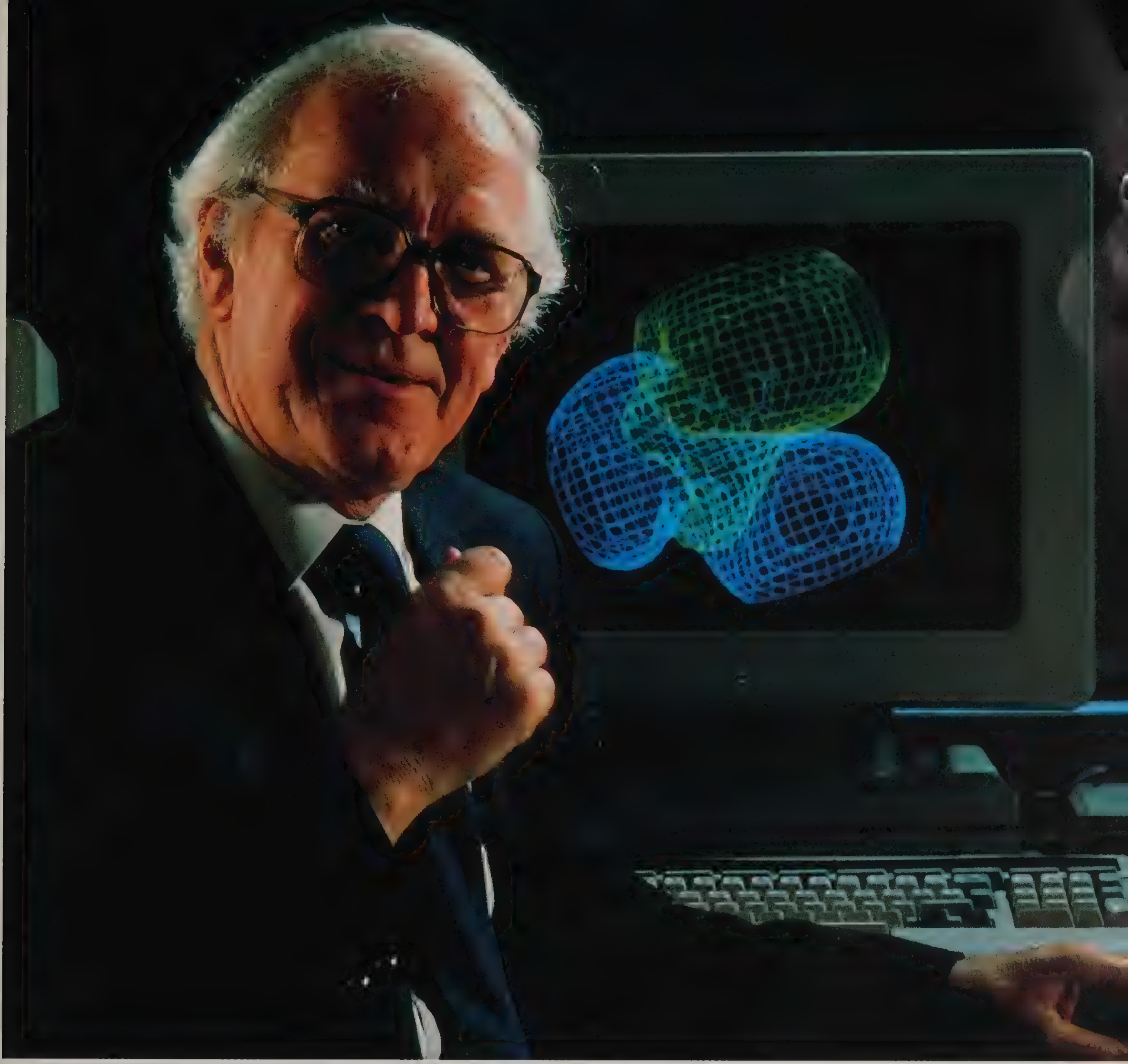
Research conducted by Zeneca, Glaxo-Wellcome, SmithKline Beecham and Fisons has led to the development of semi-synthetic penicillins and cephalosporins, both powerful antibiotics; vaccines; and new treatments for asthma, migraine, coronary heart disease and arthritis.

Acrylic acid is a commodity chemical that is polymerised to produce a wide range of speciality polymers such as flocculating agents, thickeners, absorbents and fibre sizing agents. The ammonium salt is currently produced by ammonia neutralisation of acrylic acid which can itself be produced by chemical hydrolysis of acrylonitrile. A LINK project between researchers at Huddersfield University and Allied Colloids Ltd, has shown that ammonium acrylate can be made enzymatically by immobilised bacteria in a bioreactor. The project has provided information on generic technologies relating to bioreactor design and control, applicable to a wide range of biotransformations.



One of the world's most successful anti-arthritic drugs – Ibuprofen – was developed by British pharmaceutical manufacturers, The Boots Company plc. Here one of the company's research scientists further develops new formulations of the drug using a liquid chromatograph mass spectrometer to measure trace amounts of the drug in biological fluids.





Sir James Black has pioneered a truly scientific approach to drug design, and in the process discovered two of the most important drugs now in use. His approach has been to draw up a precise biochemical specification for the new drug, and then purpose build the molecules accordingly. His method has led to the production of propanol, the first in a new class known as beta-blockers, which block the action of adrenalin on the heart. A similar approach led to the development of cimetidine, used to treat stomach ulcers by blocking the hormone that causes the secretion of stomach acid.

Government-funded researchers at London University have developed a material to mimic the mechanical properties of real bone. This new man-made 'artificial bone' is a composite of hydroxyapatite and polyethylene. It is estimated that an artificial hip made from this material will last for about 25 years. At present a patient can expect a metal artificial hip to last for around 15 years.

Clinical trials, funded by industry, are in progress and some of this artificial bone material has recently been used successfully to reconstruct bone in the human face. Britain now leads the world in the development of artificial bone.

Glaxo-Wellcome, Britain's biggest pharmaceuticals company, manufactures Zantac, the world's best-selling medicine, which is used in the treatment of gastric ulcers. The company has developed several other new drugs, including Zofran, an anti-nausea drug used to counter the unpleasant side effects of cancer treatments, and drugs to treat migraine that stimulate receptors in the brain. It is at present conducting research into drugs for controlling certain viral diseases and cancers by regulating malfunctioning genes.

Glaxo-Wellcome's drug zidovudine (AZT) is still the only anti-viral agent for the treatment of HIV infection that is approved in Britain and overseas. Zoladex, a drug made by Zeneca to treat prostate cancer, is being developed for use in breast cancer and benign gynæcological disorders.

SmithKline Beecham, which manufactures four of the world's top-selling antibiotics, has developed Augmentin, used to treat a range of infections that have become resistant to antibiotics.

Environmental and Earth Sciences

Global Environment

Water pollution can occur at any time and its source may be difficult to identify. This floating system, called Merlin, can instantly report any pollution it detects. Here it is being primed for operation to allow its probes to detect, sample and report on pollution in several different ways. Merlin can be used either as a single unit or as one of a linked radio network.

GROWING national and international pressures for higher environmental standards and the need to halt the degradation of the environment have resulted in greater emphasis on environmental research. Britain spends large sums on such research in both the private and public sectors.

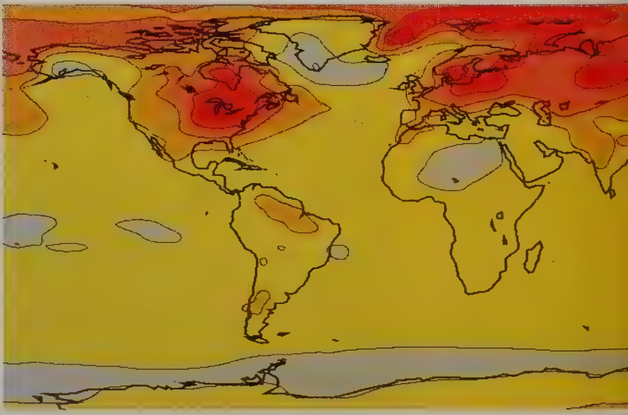
While environmental research plays a part in the work of all the research councils, the lead agency is the Natural Environment Research Council (NERC), much of whose work is done in collaboration with major international programmes on global environment issues. British scientists play a leading role in research on assessing and repairing the environmental harm caused by pollution, and there is a large R & D effort, supported by the Government, to improve the technology of pollution control.

Earth observation, the centrepiece of Britain's civil space policy, makes a vital contribution to many environmental programmes, both national and international, involving geology, land use, pollution control, and weather and climate studies. For details, see pp. 18 – 19.

Global Atmospheric Modelling Programme

The NERC supports a consortium of five universities on a project to model the atmosphere using computers. Through such models, climatologists can predict how a gas introduced into the atmosphere at one point is

A computer generated map of global warming from the UK Meteorological Office. It predicts the surface air temperature increase during northern winter (December to February) that would follow a doubling of the present levels of CO_2 emission in the atmosphere. Temperature increases are colour-coded from pale yellow (0 – 2°C) to red (8 – 12°C).



distributed in varying amounts around the globe.

The project is concentrating on the natural variability of the atmosphere and its response to greenhouse 'forcing', and the dynamics and prediction of ozone depletion. Research has begun into the processes controlling the life cycles of atmospheric pollutants in the stratosphere and pollution problems nearer the ground. Britain is thus contributing considerably to the vital task of trying to understand the factors involved in global warming and in the potentially damaging changes in the atmosphere.

Scientists from Sheffield University have developed new techniques to manipulate the weather artificially in order to create tomorrow's climate today. These experiments are enabling the scientists to show how existing vegetation and potential plant invaders may behave in a future 'greenhouse' atmosphere. Climate experts have suggested that by the year 2050 mean temperature may rise by as much as three degrees Celsius, summers may become warmer and drier, rainfall may rise or fall by 20 per cent and extremes such as summer drought and late frosts may occur more frequently.

The NERC-funded team at Sheffield has created the predicted climatic conditions by laying electrically heated cables on the surface of the experimental field site. The cables maintain temperature in the experimental plots at three degrees Celsius above the prevailing conditions throughout the winter and early spring. Drought conditions have also been created by using automatically operated rain shelters which slide over the plots as soon as rain starts and slide away when the rain stops.

Already some species originating from southern England are showing benefits from raised winter temperature and summer drought. For example, the wild carrot plant, not normally found in the field site, is doing well in drought and higher temperature conditions but, by contrast, bird's foot trefoil and wall pepper plants appear to be extremely vulnerable to late frosts.

The Terrestrial Initiative in Global Environment Research (TIGER)

This NERC initiative, started in 1991, is the largest study of the natural environment yet undertaken in Britain and will make a significant contribution to a number of global change projects. TIGER focuses on the response of nature to effects such as global warming and stratospheric ozone-depletion at sites in Britain and in selected tropical sites. In 1993 it published new findings that plants in a future 'greenhouse' atmosphere may breathe out less water vapour than previously predicted. This could result in a drier world, with reduced cloud formation and less rainfall. TIGER's two research sites in Britain are complemented by others in Amazonia, west and Sahelian Africa and Canada. Experiments on energy/water balance carried out in the Amazonian rainforest are now being used in global climate models.

The Travel Well, a compact portable water purifier, effectively treats contaminated water, removing all parasites, bacteria and viruses in less than four minutes. Designed and manufactured by Pre-Mac (Kent) Ltd, the unit has three filtration and two disinfecting stages which produce water that is colourless, odourless and safe.

Environmental and Earth Sciences

Earth, Marine and Polar Sciences

One of the two research ships of the British Antarctic Survey (BAS), seen offshore at the Rothera Research Station. The BAS has undertaken a programme of shipborne marine biological research for over 15 years.

The NERC carries out strategic surveys of Britain's landmass and offshore regions, which give essential information on mineral resources, water resources, environmental protection, natural hazards and land use. A comprehensive geological survey of Britain's inner continental shelf, completed by the British Geological Survey in 1992, has yielded a detailed picture of its margin and associated natural resources. Britain is the first country in the world to have completely mapped its offshore area in this way. A 15-year programme of onshore re-survey was begun in 1991 and has already revealed a new phase of mineral deposits in Cornwall.

The NERC's Offshore Survey and Geophysical Monitoring project investigates the mineral resources and seismic hazards of Britain's offshore areas. Two unique deep-ocean seismic experiments were carried out during 1992; the results will aid geological interpretation of former plate collision zones.

Ocean Drilling Program

Britain participates in the Ocean Drilling Program, the world's largest and most successful international scientific research project in the Earth sciences. Current studies involving British scientists include those on the geology of ocean basins, mid-ocean ridges, marine sedimentation and ocean circulation.

Recent work by NERC-supported scientists from drill sites off western Canada have led to the discovery of a large metal sulphide deposit which has apparently formed on the sea-floor. The results have changed accepted views of the processes involved in the formation of ancient mineralised sulphide deposits and might be applied to exploration of land-based deposits, which would be of economic value.

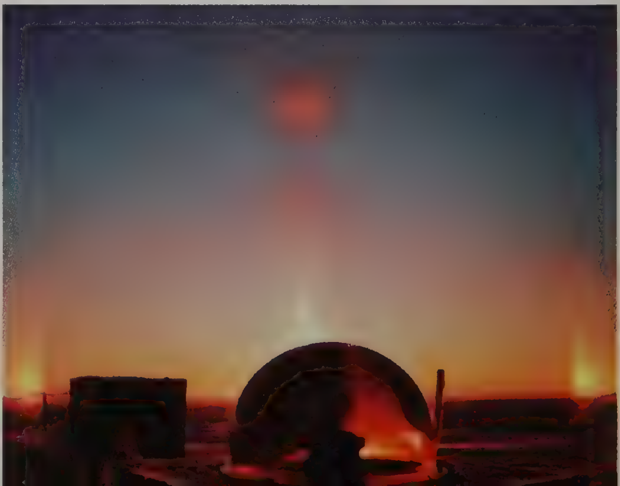
Marine Sciences

The Biogeochemical Ocean Flux Study (BOFS), begun in 1988, has now been completed. The project looked at how carbon dioxide is absorbed by the oceans and buried in the sea floor sediments, helping to stabilise the greenhouse effect. Comparisons of recent results show a large variation in the amount of animal and plant debris reaching the sea floor. Half of this variation can be linked with changes in ocean circulation, showing that biological variability in the open oceans is governed by environmental changes that can be studied in greater detail. Funds are now being made available for a new project on how plankton in the North Atlantic react to their environment and their role in climate change.

The NERC's Land Ocean Interaction Study (LOIS) is a major new project to study the dynamics of coastal environments and the flow of various materials into and across the coastal zone from the air, the land and rivers and from the sea. The study will provide the basis for predictions of the impact of future natural and man-made changes on the coasts.

The Fine Resolution Antarctic Model (FRAM), set up by the NERC to simulate 16 years of ocean dynamics, has now been

An auroral display – resulting from the interaction of sunlight and ice crystals in the lower atmosphere – seen at the British Antarctic Survey's Halley Station, where scientists study the processes that occur in geospace, a region extending from about 100 km to over 50,000 km from the Earth's surface. The aurorae are monitored using a camera with a 'fish-eye' lens – shown here – which takes photographs of the whole sky at regular intervals.



A scientist with the British Antarctic Survey analysing block of solid ice ontaining trapped bubbles f atmospheric gases, in a roject to establish etailed records of climate hrough the past several housand years in the Antarctic.

completed. Its discoveries are making oceanographers revise their thinking on how oceans transport heat around the Earth, thereby making a vital step towards climate prediction.

A new Ocean Circulation and Climate Advanced Modelling Project (OCCAM) has been developed to improve global ocean models for research into climate change on timescales ranging from a few months to 50 years.

Polar Sciences

The British Antarctic Survey (BAS), one of the NERC's research institutes, has been carrying out scientific research in Antarctica for many decades. It has five permanent research stations in Antarctica, carrying out continuous research and monitoring. The BAS collaborates with 21 other countries active in Antarctic research, as part of the Antarctic Treaty, and its research covers climate change, notably the depletion of the ozone layer over the Antarctic, global warming, past climate patterns (through ice-core analysis), oceanographic processes, and geospace observations.

Scientists of the BAS were responsible for discovering the hole in the ozone layer above Antarctica in 1985. Using equipment developed by one of its predecessors in the 1920s, they discovered the lowest concentration of ozone ever recorded on the Earth. The discovery, corroborated later by other observations, was the catalyst for the Montreal Protocol, an international agreement to phase out the production of ozone-depleting chemicals such as CFCs.

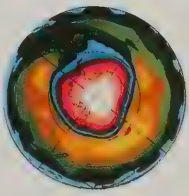
In late 1992 the BAS started a major project investigating the role of the ice-covered Southern Ocean in regulating levels of carbon dioxide in the atmosphere. The data collected will be used to produce a mathematical model of carbon cycling at the ice edge. This research is part of an international programme.

Research by the BAS has also covered the northern polar regions and includes collaboration with the international Greenland Ice-core Project.

The Greenland Ice-core Project

In July 1992 a team of European scientists from eight nations, organised by the European Science Foundation, including scientists from the BAS, succeeded in drilling an ice core through the Greenland ice sheet down to bedrock 3,000 metres deep. First results show that the deepest layers of ice provide a record of climate conditions as far back as 200,000 years. The records are stored in the form of gas bubbles and dust particles which were contained in the snowfall from which each layer of ice was created.

Chemical and physical analysis of the core is yielding vital information on climatic changes throughout the entire glacial to interglacial cycle, in unprecedented detail. Analyses made at the time of drilling – including continuous dielectric drilling profiling by the British scientists – have confirmed that during the last ice age there was a series of major climatic reversals marked by extremely rapid flips from warm to cold conditions. Research is now focused on ice deposited during the last interglacial cycle, widely believed to be somewhat warmer than the present, and hence a possible analogue for a future warmer world.



Map showing the total atmospheric ozone concentration in the southern hemisphere on 6 October 1993. The colours represent the ozone concentration in Dobson Units (DU). The large, oval-shaped blue, pink and white area is the 'ozone hole' over the Antarctic, where ozone readings were below 250 DU. The depletion in 1993 was the worst to that date; the centre of the 'hole' recorded less than 100 DU, a decrease of at least 150 DU (60%) compared with pre-1975 values.

Conservation

Many species of plants and animals are disappearing rapidly through over-exploitation or loss of habitat. As part of its response to the 'Earth Summit' at Rio de Janeiro in 1992, the Government has published a Biodiversity Action Plan outlining Britain's role in conserving biological diversity at home and overseas. Published in January 1994, the plan provides a strategy for the next 10 to 20 years. In it the Government commits itself to conserve, and where possible enhance:

- the overall populations and natural ranges of native species and the quality and range of wildlife habitats and ecosystems;
- internationally important and threatened species, habitats and ecosystems;
- species, habitats and natural and managed ecosystems that are characteristic of local areas; and
- the biodiversity of natural and semi-natural habitats where this has been diminished over recent decades.

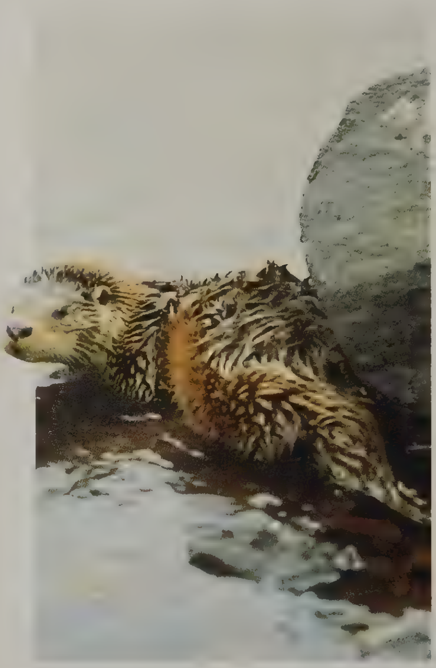
Conservation within Natural Habitats

Considerable research and management is carried out to encourage the recovery of populations of species threatened with extinction. In 1978, for example, the otter seemed in danger of extinction in England. Of 3,200 stretches of river studied, only 1 in 16 were found to support this animal. Pesticides, pollution and hunting were blamed for the decline. By 1993, however, a study funded by the Vincent Wildlife Trust showed a very different picture: otters were found in one in six sites studied, including the River Thames.

Improvement in the quality of river water, a ban on the use of pesticides such as DDT, and a ban on otter hunting has enabled otters to spread from existing populations in England, Scotland and Wales. Nature conservation agencies and the National Rivers Authority have helped the recovery by encouraging suitable management of river banks and by introducing young otters to rivers where the original populations had died out or where the existing population was so small it was unlikely to recover without new recruits.

Conservation outside Natural Habitats

Britain has historically played a leading role in the development of techniques for conserving species away from their natural habitats (*ex situ*). A number of institutions are internationally recognised as among the world leaders in this field, including the Royal Botanic Gardens, Kew, in Surrey, which has been at the forefront of botanical research and plant conservation for 200 years. Funded mainly by a grant from MAFF, Kew houses the largest and most diverse collection of living plants, and the most comprehensive research collection of dried plants in the world. It has the world's largest seed bank for wild origin species and is active in programmes to return endangered plant species to the wild.



The Eurasian otter, *lutra lutra*, is found from the west of Ireland across Europe and Asia to Japan. The decline of the species in Britain was noticed in the early 1960s in central and southern parts of the country, but not in the north and west. The habitat requirements of Britain's otters in rivers and in coastal areas, such as Shetland where this otter was studied, are well known from research by NERC's Institute of Terrestrial Ecology.

Today, as natural plant habitats throughout the world are being destroyed and plants are becoming extinct, a priority of the research at Kew is to assess the value of whatever is being lost, so that a way can be found to reduce and reverse the rate of destruction of species. Kew participates in joint research programmes in 52 countries.

The captive breeding program, coordinated by the Invertebrate Conservation Centre at London Zoo, has resulted in the return of some of these snails to the world's smallest wildlife reserve on the Polynesian island of Moorea. There are over 10,000 snails in the captive programme, representing twenty-four *Partula* species. The success of the programme depends to a great extent on unique colony management software called CERCI which was developed by London Zoo to record and analyse the vast quantities of demographic and genetic information on the captive Partula, thus helping to maintain a viable captive population fit for eventual reintroduction into the wild.

Examples of *ex situ* conservation

- *The Kew seed bank contains nearly 4,000 flowering plant species. Seeds, collected from most parts of the world, are dried by exposure to low relative humidity and then stored in air-tight rooms and deep frozen. This improves and extends the lifespan of the seeds. During expeditions as many types of plant seeds as possible are collected in an area, because it is impossible to predict which ones will eventually prove useful and also to ensure a broad genetic base. Sufficient seeds are left to regenerate in future years. All expeditions are undertaken in collaboration with host governments and are underpinned by legal Memoranda of Understanding and within the guidelines of the Biodiversity Convention.*
- *Many micro-organisms, including viruses, bacteria, protozoa, and most algae and fungi, are conserved in culture collections. These collections have a research and applied value, particularly in industry – for example, the National Collection of Industrial and Marine Bacteria (for industrially significant bacteria). Research is carried out at British microbiological institutes to enhance preparation techniques and long-term storage methods – especially with liquid nitrogen. New protocols for preservation are being developed using cryogenic stage microscopy, enabling some species to be preserved satisfactorily for the first time.*
- *Many zoos in Britain play a vital role in reintroduction programmes for species of international importance, such as the Arabian Oryx, Scimitar-horned Oryx, Arabian Gazelle, Mauritius Kestrel and Pink Pigeon. Some have a wider role providing management plans for areas and species of conservation interest. London Zoo, for example, is involved in 52 nationally and internationally co-ordinated captive breeding programmes for exotic species and manages 29 such programmes.*

Energy Research

The world's first tension leg platform (TLP), installed in the North sea in 1984. Designed and built in Britain, the TLP paved the way for deep sea oil production.

Mounting evidence linking global warming with carbon dioxide (CO_2) emissions has led to the need to make energy production, and within that, power generation, less damaging to the environment.

Clean Coal Technologies

Britain has pioneered the most important advance in coal combustion this century – the technique of fluidised bed combustion.

The technique enables the use of a wide range of coals, including low-quality coals, and – with the addition of limestone or dolomite to the bed – reduces polluting sulphur emissions to the atmosphere. The British technology is employed under licence in a number of countries.

One such advanced system is the British Coal topping cycle programme, in which some of the coal is converted to hot gas for use in a gas turbine and the remaining char is burnt in a fluidised bed to raise steam for a conventional steam turbine. This offers to reduce CO_2 emissions from coal-fired power stations by 20 per cent and is to be developed by an industry-led consortium. The Government supports a growing R & D programme into renewable forms of energy, such as wind power, tidal power and biofuels (where projects aim to obtain energy from the combustion of forest residues, straw and coppice wood and from gas present in landfill sites).

Scientists are assessing the possibility of

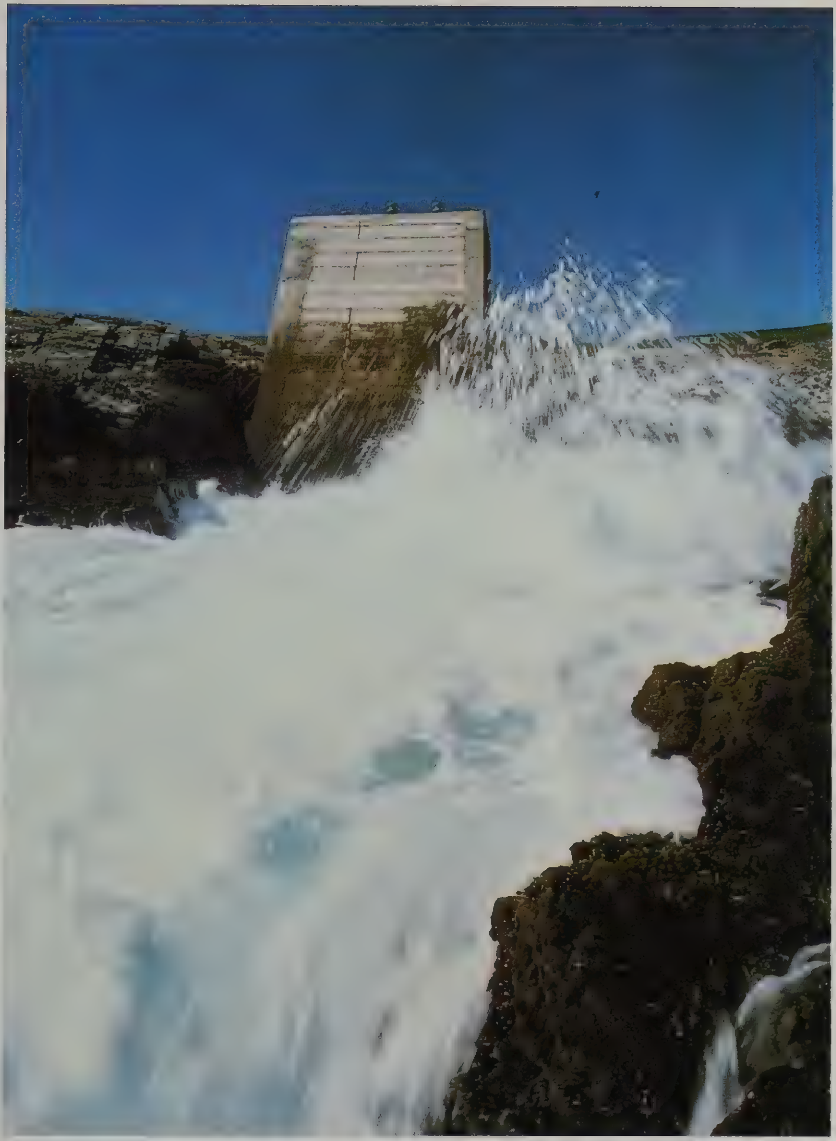
Tidal Current Generator

A consortium made up of Scottish Nuclear, the IT Power Company and NEL (formerly the National Engineering Laboratory) is developing the world's first tidal current turbine, designed to harness the sea's energy and convert it into electricity. The turbine is similar in principle to a windmill, but instead of being driven by the wind it is submerged in the sea and turned by the flow of water stemming from the rise and fall of the tides.

A pilot scheme involves the development of a small 10-kilowatt turbine with a 4-metre rotor. This will be tested at sea as the forerunner for much larger versions.

The rotor will drive a generator in a streamlined, watertight casing and its output will charge a bank of batteries in a buoy. Full-sized examples, with outputs of 1 megawatt or more, would be linked to the onshore electricity grid by marine cables.

BP's petrochemicals complex at Grangemouth, near Edinburgh, is one of the world's largest and most advanced, producing around 1 million tonnes of chemicals and plastics a year. Two recent developments include a new ethylene production plant and a project to develop technology for recycling plastic waste back into raw materials.



Prototype wave-powered electricity generator under evaluation near Portnahaven on the island of Islay, Scotland. The device is built at the head of a natural rock gully and encloses a column of sea water. Waves entering the gully are channelled in towards it causing the column of water to rise and fall. This forces air through a Wells turbine which turns in the same direction whichever way the air is flowing, driving a 200 kW electricity generator. The device was designed and developed by researchers at Queen's University, Belfast.

siting large numbers of wind turbines offshore for large-scale electricity production, through the development of floating support structures.

Other Technologies

The Government-funded Clean Technology Programme, launched in 1992, aims to stimulate research leading to new technologies to prevent pollution caused by industry and agriculture. It concentrates on new, inherently clean processes.

Recent achievements include a new test method to improve the immunity of vehicles to electromagnetic interference; image sensing and processing on a single silicon chip; and contributions to a prototype shore-based wave power device. Scientists from Southampton University have developed a system for separating oil from water using hydrocyclones. This system has transformed the efficiency of removing oil from water and since 1992 has been produced commercially for offshore oil platforms.

Chemical Pollutants

In an EU-funded project, scientists at Kent University are collaborating with scientists from Germany, the Netherlands and Belgium to find a more efficient way of cleaning up water and land contaminated by toxic polychlorinated biphenyls (PCBs), a major source of pollution in all developed countries. Once used widely in the manufacture of electrical transformers and for other industrial purposes, these chemicals are now banned.

Current technologies for cleaning up land and water contaminated by PCBs are considered unsatisfactory and the research project aims to devise a bio-reactor system (one using micro-organisms) to break down the PCBs completely .

In March 1992 ICI scientists launched the world's first solvent-free emulsion household paint. Until then such paints had included solvents known as volatile organic compounds. These evaporate into the atmosphere as the paint dries, and in sunlight can react in the lower atmosphere with nitrogen oxides to generate photochemical smog. In October 1992 ICI launched the world's first water-based metallic paint for cars.

Researchers gathering samples from a lake near a water treatment works where a pilot plant is testing the use of natural microbes (bacteria) to tackle the problem of environmentally-harmful liquid waste.

A wind turbine at Richborough power station, Kent, with the River Stour in the foreground.

Twentieth Century Achievements

Early Achievements

A few examples of British pioneering achievements in science and technology are given below.
Britain cannot claim sole credit for all the achievements listed.
Some owe their success to international collaboration or to earlier developments overseas.
In others, inventions in Britain have been perfected elsewhere.

Physics and Astronomy

At the beginning of the century:

- Ernest Rutherford pioneered the science of nuclear physics; his research showed that radioactivity is produced by the disintegration of atoms, thus demonstrating the nuclear structure of the atom.
- JJ Thomson discovered that cathode rays were rapidly moving particles (electrons) of negative electric charge.
- William and Lawrence Bragg discovered the method of determining the structure of crystals by means of X-rays.
- In the 1920s CTR Wilson invented the cloud chamber method of photographing the tracks of charged particles such as alphaparticles, protons and electrons, thus making it possible to follow the movement and interaction of atoms.
- The existence of neutrons was first proved by James Chadwick, and the groundwork for quantum electrodynamics was laid by Paul Dirac in the 1930s.
- In 1951 John Cockcroft was the first to split the atomic nucleus by artificial means, using an accelerator.
- Bernard Lovell pioneered the science of radio-astronomy in the 1950s.
- In the late 1960s the science of radio-astrophysics was pioneered by Martin Ryle and Antony Hewish. In 1967 their co-worker, Jocelyn Bell, discovered pulsars.

Chemistry

In the 1950s:

- Archer Martin and Richard Synge invented chromatography as a method of identifying and separating chemical compounds.
- RGW Norrish and Lord Porter developed the flash photolysis technique of analysing extremely fast chemical reactions.
- Major developments in the X-ray analysis of complex molecules included the work of:
  - Max Perutz and John Kendrew, who explained the detailed structure of hæmoglobin and myoglobin;
  - Dorothy Hodgkin, who determined the structure of penicillin and vitamin B12.

Medicine and Genetics

- The hormone insulin was isolated by JJR Macleod in 1923 and its structure explained by Frederick Sanger in 1958.
- In 1929 Frederick Gowland Hopkins was the first to show that life cannot be maintained on protein, fats and carbohydrates alone but that accessory food factors (now called vitamins) are also essential.
- Interferons – proteins produced in the body to fight infections – were first isolated and named by Alick Isaacs and colleagues in 1957. They have been used to treat forms of cancer and can prevent transmission of some cold viruses.
- In 1953 Francis Crick, together with James Watson of the United States, made one of the most important scientific discoveries when they discovered the structure of DNA, the substance which carries the genetic code at a molecular level. Working at the MRC's laboratory in Cambridge, from the experimental work of Maurice Wilkins and Rosalind Franklin of London University, Crick and Watson proposed the double helix structure for DNA which explains heredity in chemical terms.
- The work of Peter Medawar in the 1950s on acquired immunological tolerance made possible the first successful kidney transplants.
- Artificial hip joints were developed and first fitted by John Charnley at Wrightington Hospital, Lancashire, in 1960.

Mechanical Engineering

- The world's first tank was built and used by the British War Office in 1916.
- The first practicable jet engine was designed and patented by Sir Frank Whittle in the 1930s. Rolls Royce built the world's first propeller-turbine (or turboprop) engine in 1945 and the world's first turbofan engine in the 1950s.
- The hovercraft was invented by Christopher Cockerell in the mid-1950s.
- Joseph Bamford invented the world's first backhoe loader (the 'JCB') in the 1950s, combining a hydraulically-operated excavator arm with a loader.

Electrical Engineering, Electronics and Optics

- The first practical demonstration of television was given by John Logie Baird in 1926; in 1938 Logie Baird first demonstrated broadcast colour television pictures.
- The world's first high-pressure mercury lamp – a forerunner of the fluorescent tube – was developed by the General Electric Company in 1932, as was cold cathode and sodium lamp street lighting in the 1950s, and tungsten halogen lamps in 1961.
- Long-wave radar was first used for aircraft detection by Robert Watson Watt in 1935.
- In 1943 Max Newman, Donald Michie and Alan Turing built the first electronic computer, Colossus 1, which was used for breaking enemy communications codes in the Second World War.
- Harold Hopkins – who also invented the zoom lens in 1947 – first used fibre optics in a medical endoscope (to see inside patients' bodies) in 1954.
- The first laser to be used as an industrial tool was made by Ferranti in 1963.
- The Post Office's first Earth station was the first to transmit live television pictures from Europe by satellite.

General Chemicals

- Dunlop invented latex foam in 1929. In the 1930s ICI invented 'Perspex' and discovered and subsequently produced polythene (polyethylene), possibly the world's most widely used plastic for food packaging.

Pharmaceuticals

- Alexander Fleming discovered penicillin in 1928; it was first produced for medical use in 1940.
- Cephalosporin C, an antibiotic active against a wider range of disease-causing organisms than the naturally occurring penicillins, was first isolated by Edward Abraham in 1953.
- In 1962 the first beta-blocker successful in treating angina was introduced, having been synthesised by James Black at ICI.

Some Recent Achievements

A few of the more important scientific developments and inventions made by Britain over the last 25 years – not described elsewhere in this book – are outlined here.

Physics and Astronomy

- Brian Josephson's theoretical work in the early 1970s on superconductivity has since been used to develop higher-speed computers.
- In the 1980s Michael Green helped to develop the 'superstring' theories, which see the fundamental building blocks of matter and energy in the universe as infinitesimal 'strings' rather than points.
- In 1985 scientists at Heriot-Watt University, Edinburgh, invented the transphasor, a type of optical transistor now forming the basis of a new generation of optical computers that are significantly faster than their electronic counterparts.
- Much of the work on black holes has been carried out by Stephen Hawking, the Cambridge astrophysicist who in 1974 showed that black holes can emit radiation with a thermal spectrum.
- The first coded mask X-ray telescopes were built at Birmingham University for the United States Spacelab 2 mission in 1985.
- The world's first scanning laser microscope able to operate at some distance from its subject was built at the laboratories of the United Kingdom Atomic Energy Authority in 1984 for use with radioactive materials.

Chemistry

- In 1985 Harry Kroto of Sussex University discovered a new form of carbon – the C60 fullerenes. Subsequent research by British scientists has revealed the detailed structure of the carbon, which has the potential to form the basis of an ideal lubricant.

Medicine and Genetics

- In 1975 John Hughes and Hans Kosterlitz of Aberdeen University succeeded in isolating enkephalin, a brain chemical with some of the properties of morphine, which might be used eventually as a natural painkiller.
- In 1975 César Milstein and colleagues, working at the MRC laboratory in Cambridge, made one of the most important scientific discoveries of the century by producing monoclonal antibodies (antibodies produced from a single parent cell) to order. This discovery transformed biological research and created biotechnology.
- The first commercial brain and body scanner relying on computer-assisted tomography (CT) was made by EMI in 1972. Based on the technique developed by Godfrey Hounsfield, CT uses reassembled X-ray information to produce detailed cross-sections of the head and body.
- The 1970s also saw the first detailed cross section images of the body produced by magnetic resonance imaging (MRI). This technique, which involves subjecting matter to a powerful magnetic field and passing radio waves through it, can generate images of soft tissue that do not show up well on X-rays. A complete analytical instrument for MRI was developed by Oxford Instruments, working with biochemists from Oxford University who used MRI clinically for the first time in 1981.
- In 1977, when working on a virus responsible for the common cold, Richard Roberts and the United States researcher Phillip Sharp independently discovered that genes are split up and can comprise several DNA segments.
- Aaron Klug's application of electron microscopy to the study of the structure of DNA and certain viruses in the early 1980s contributed further to understanding how cancers develop.
- The technique of in vitro fertilisation, pioneered by Patrick Steptoe and Robert Edwards, led to the birth of the world's first 'test-tube baby' in Oldham in 1978.

Agriculture and Food

- BBSRC institutes in Cambridge were the first to achieve the birth of a calf following embryo transfer in 1966 and birth from an embryo frozen in liquid nitrogen in 1973.
- In 1988 BBSRC and MAFF scientists were the first to show that bovine spongiform encephalopathy (BSE) is a transmissible disease.

Materials and Metals

- Float glass, developed by the Pilkington Group in the 1950s, had replaced plate glass in the construction and transport industries by 1970. The Group has become the world's largest makers of float glass and has licensed the process worldwide.
- Sialon ceramic, one of the strongest known ceramic materials, was developed in 1970 by scientists at Newcastle University. It is used as a high-speed cutting tool for machining metals.
- Research at the Royal Aerospace Establishment at Farnborough led to the development in the 1980s of aluminium alloys containing lithium, which are stronger and lighter than existing alloys and are used in aircraft manufacture worldwide.

Electronics and Communications

- The world's first distributed array processor for computers was developed by ICL in the 1970s. This can carry out over 100 million calculations a second and is used to solve three-dimensional field problems in many areas of social and scientific study.
- The 'Micropad', originally developed at the National Physical Laboratory and launched in 1979, was the world's first computer terminal to accept direct handwritten input.
- Long-life liquid-crystal displays (LCDs), which are widely used in digital watches and pocket calculators, were first tested in the 1970s at the Royal Signals and Radar Establishment, incorporating compounds produced at Hull University.
- In the 1970s BBC and Independent Broadcasting Authority engineers pioneered the development of teletext, in which pages of information are broadcast and may be viewed on television screens.

Energy

- In the late 1970s the BP Research Centre developed a safer, cleaner and more efficient method of disposing of flare gas from offshore installations, refineries and petrochemical plants. It is estimated to have saved more than £100 million in platform construction costs and has been exported to many countries.
- Ferranti pioneered the world's first use of inertial navigation for mapping oil wells under the seabed in 1977.

Useful Addresses

In-country inquirers refer to the nearest British mission

Ministry of Agriculture, Fisheries and Food
3 Whitehall Place,
London SW1A 2HH
Tel 0171-270 3000

Ministry of Defence
Main Building,
Whitehall,
London SW1A 2HB
Tel 0171-218 9000

Department of the Environment
2 Marsham Street,
London SW1 3EB
Tel 0171-276 0900

Foreign & Commonwealth Office
King Charles Street,
London SW1A 2AH
Tel 0171-270 1500

Department of Health
Richmond House,
79 Whitehall,
London SW1A 2NS
Tel 0171-210 3000

Office of Science and Technology
(Cabinet Office),
Albany House,
84 – 86 Petty France,
London SW1H 9ST
Tel 0171-270 1234

Overseas Development Administration
94 Victoria Street,
London SW1E 5JL
Tel 0171-917 7000

Department of Trade and Industry
151 Buckingham
Palace Road,
London SW1W 9SS
Tel 0171-215 5000

British National Space Centre
Bridge Place, 88 –
89 Eccleston Square,
London SW1V 1PT
Tel 0171-215 0806

Royal Botanic Gardens Kew
Richmond,
Surrey TW9 3AB
Tel 0181-332 5000

Royal Society
6 Carlton House
Terrace, London
SW1Y 5AG
Tel 0171-839 5561

The British Council
10 Spring Gardens,
London SW1B 2BN
Tel 0171-930 8466
Contact for local Council Office addresses

UK Research and Higher Education European Office
Rue de la Loi 83,
BP1O,
1040 Brussels,
Belgium
Tel 00 32 2 230 5275

Research Councils

Biotechnology and Biological Sciences Research Council
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Swindon, Wiltshire
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Council for the Central Laboratory of the Research Councils
Chilcot, Didcot,
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Tel 01235 821900

Economic and Social Research Council
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North Star Avenue,
Swindon, Wiltshire
SN2 1UJ
Tel 01793 413000

Engineering and Physical Sciences Research Council
Polaris House,
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Swindon, Wiltshire
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Tel 01793 444000

Medical Research Council
20 Park Crescent,
London WIN 4AL
Tel 0171 636 5422

Natural Environment Research Council
Polaris House,
North Star Avenue,
Swindon, Wiltshire
SN2 1EU
Tel 01793 411500

Particle Physics and Astronomy Research Council
Polaris House,
North Star Avenue,
Swindon, Wiltshire
SN2 1SZ
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General publications

Realising Our Potential: A Strategy for Science, Engineering and Technology
Cm 2250 HMSO

International Comparisons of Research and Development Spending
Office of Science and Technology
HMSO

Biodiversity: The UK Action Plan
Cm 2428 HMSO

This Common Inheritance: Britain's Environmental Strategy
Cm 1200 HMSO

The Health of the Nation
Cm 1523 HMSO

Annual Publications

Forward Look of Government-funded Science, Engineering and Technology
HMSO

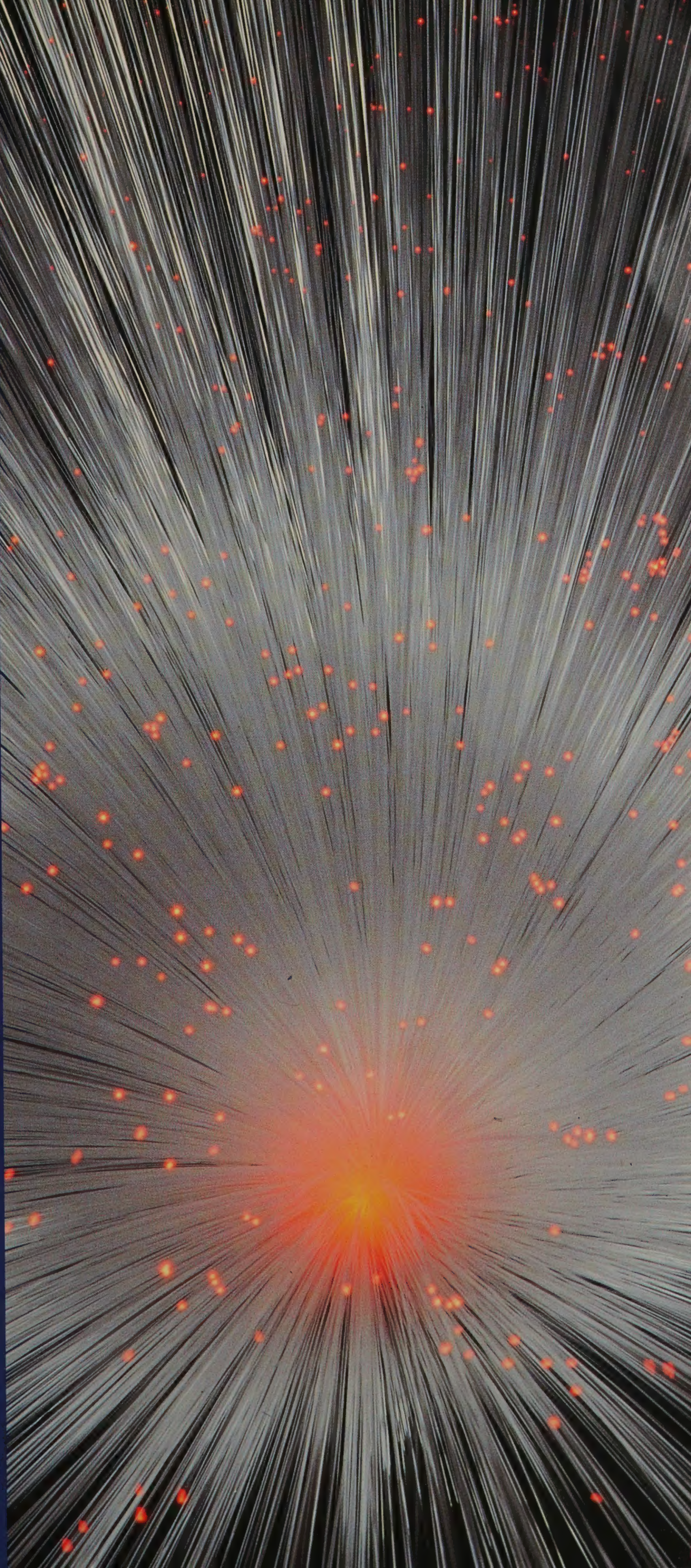
Each research council publishes an annual report, available from the addresses given above.

All government departments can be accessed through the Government Centre for Information Systems (CCTA's) web pages. The address is:

http://www.open.gov.uk/

Abbreviations

BAS	*British Antarctic Survey*
BBSRC	*Biotechnology and Biological Sciences Research Council*
BNSC	*British National Space Centre*
CERN	*European Laboratory for Particle Physics*
CCL	*Council for the Central Laboratory of the Research Councils*
CFCs	*chlorofluorocarbons*
CSA	*Chief Scientific Adviser*
CST	*Council for Science and Technology*
D Emp	*Department of Employment*
DH	*Department of National Heritage*
DOE	*Department of the Environment*
DOT	*Department of Transport*
DRA	*Defence Research Agency*
DTI	*Department of Trade and Industry*
EISCAT	*European Incoherent Scatter Radar Facility*
EPSRC	*Engineering and Physical Sciences Research Council*
ERS	*European Remote Sensing*
ESA	*European Space Agency*
ESRC	*Economic and Social Research Council*
EU	*European Union*
EUREKA	*European High Technology Programme*
HERA	*Hadron Electron Ring Accelerator*
MAFF	*Ministry of Agriculture, Fisheries and Food*
MERLIN	*Multi-Element Radio-Linked Interferometer Network*
MoD	*Ministry of Defence*
MRC	*Medical Research Council*
NASA	*National Aeronautics and Space Administration*
NERC	*Natural Environment Research Council*
NPL	*National Physical Laboratory*
ODA	*Overseas Development Administration*
OECD	*Organisation for Economic Cooperation and Development*
OPSS	*Office of Public Services and Science*
OST	*Office of Science and Technology*
PPARC	*Particle Physics and Astronomy Research Council*
R & D	*research and development*
RTOs	*Research and Technology Organisations*
SO	*Scottish Office*
SuperJANET	*Super Joint Academic Network*



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